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BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF CALIFORNIA

Order Instituting Rulemaking to Consider Strategies and Guidance for Climate Change Adaptation.	Rulemaking 18-04-019 (Filed April 26, 2018)

SAN DIEGO GAS & ELECTRIC COMPANY'S (U 902-E) RESPONSE TO ADMINISTRATIVE LAW JUDGE'S RULING ORDERING FILING OF EXISTING VULNERABILITY ASSESSMENTS PERFORMED BY INVESTOR OWNED UTILITIES

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November 25, 2019

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Pursuant to the November 14, 2019 Ruling of Administrative Law Judge Thomas, San Diego Gas & Electric Company (SDG&E) hereby identifies and submits its vulnerability assessment documents that evaluate how the utility may adapt to climate change in the future by fortifying or altering its infrastructure to accommodate climate change.

I. VULNERABILITY ASSESSMENTS AND ANY DOCUMENTS THAT ASSESS HOW THE UTILITY MAY ADAPT TO CLIMATE CHANGE IN THE FUTURE

SDG&E has identified and submits the following climate change related vulnerability assessments and documents including a summary of the assessments:

Assessment	Date
South Bay Substation Relocation Project	April 26, 2013
Climate Change in the Energy Sector: Partnership for Energy Sector Climate Resilience	February 2016
Climate Resilience Plan	November 2016
Risk Assessment and Mitigation Phase (RAMP) Report (I-16-10-015)	November 30, 2016
Rising Seas and Electricity Infrastructure: Potential Impacts and Adaptation Options for San Diego Gas and Electric	August 2018
Wildfire Mitigation Plan (R.18-10-007)	February 6, 2019

ICF: Support for SDG&E Climate Adaptation: Flexible Sea Level Rise Adaptation Pathway for Montgomery Substation	February 28, 2019
Risk Assessment and Mitigation Phase (RAMP) Report (I-19-11-011)	Due: November 30, 2019

1. South Bay Substation Relocation Project

As part of SDG&E's South Bay substation relocation project, the California Public Utilities Commission contracted with Dudek to complete an Environmental Impact Report (EIR). The final EIR was prepared published in April 2013. Section D.17[1] of the report evaluated the potential impact of sea level rise on the South Bay Substation Relocation Project out to 2100

2. Climate Change in the Energy Sector: Partnership for Energy Sector Climate Resilience

This vulnerability assessment (attached) from February 2016 reviewed the projected impacts of climate change on the San Diego region with the intent to identify potential vulnerabilities in the generation and delivery of gas and electricity. The focus of this assessment was on temperature, drought and rainfall patterns, wildfires, and sea level rise.

3. Climate Resilience Plan

The Climate Resilience Plan (attached) was built on the understanding gained from the Climate Change in the Energy Sector: Partnership for Energy Sector Climate Resilience vulnerability assessment outlining the future climate change projections for SDG&E's service territory. This resilience plan applied the knowledge to measures being adopted by SDG&E.

[1] https://www.cpuc.ca.gov/environment/info/dudek/sbsrp/FEIR/D.17_Climate_Change.pdf

4. Risk Assessment and Mitigation Phase - 2016

SDG&E filed its first Risk Assessment and Mitigation Phase (RAMP) report[2] on November 30, 2016. This first formal RAMP filing identified SDG&E's baseline assessment of safety risks to the public, their employees and their systems, and what potential mitigation measures have been considered. Based on those potential mitigation measures, the utilities then proposed certain mitigation measures to further reduce identified risks. Chapter 14[3] specifically addressed Climate Change Adaptation. This chapter focused on the risk of Climate Change Adaptation and identified threats to SDG&E's gas and electric system due to an evolving climate across the San Diego region include increasing temperatures, a higher potential for wildfire occurrence, accelerated sea level rise, and changes in rainfall patterns. Controls focused on safety-related impacts (i.e., Health, Safety, and Environment) per guidance provided by the Commission in Decision 16-08-018 as well as controls and mitigations that may address reliability.

5. Rising Seas and Electricity Infrastructure: Potential Impacts and Adaptation Options for San Diego Gas and Electric

The Rising Seas and Electricity Infrastructure report[4] was prepared for California's Fourth Climate Change Assessment, prepared by ICF and Revell Coastal. The report was the result of work sponsored by the California Energy Commission (CEC). The report addressed rising sea levels threat to California's energy infrastructure and the coastal communities that it serves. This study further analyzed the exposure of SDG&E electricity assets in San Diego

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[2] https://www.sdge.com/regulatory-filing/20016/risk-assessment-and-mitigation-phase-report-sdge-socalgas

[3] https://www.sdge.com/sites/default/files/SDGE-14_RAMP_Climate_Change_Adaptation_FINAL.pdf

[4] https://www.energy.ca.gov/sites/default/files/2019-07/Energy_CCCA4-CEC-2018-004.pdf

County to climate change-driven coastal wave flooding, tidal inundation, and coastal erosion.

6. Wildfire Mitigation Plan

SDG&E's Wildfire Mitigation Plan[5] was filed in February 2019. In response to past destructive fires, SDG&E hired subject matter experts in the firefighting, fire science, and meteorology who have assisted in the development and implementation of programs to enhance situational awareness, which increases SDG&E's ability to monitor and understand the wildfire environment. With the increasing impacts from climate change, community growth, and other societal forces, SDG&E's wildfire risk management strategy will continue to evolve. Plans to expand system hardening projects and incorporate additional wildfire mitigation activities into SDG&E's resilience practices are ongoing. Section 4.6, Climate Change Adaption, identifies the expected future impacts of drought and temperature rise, projecting longer and more extreme fire seasons. Wildfire risk mitigation was included in the 2016 RAMP filing.

7. Support for SDG&E Climate Adaptation: Flexible Sea Level Rise Adaptation Pathway for Montgomery Substation

Following the "Rising Seas and Electricity Infrastructure" report sponsored by the CEC, SDG&E contracted ICF to explore the potential of flexible adaptation pathways as a strategy for mitigating climate risks specific to the Montgomery substation. The report (attached) finds additional vulnerabilities with the substation and presents a draft flexible adaptation pathway to mitigate these vulnerabilities.

8. Risk Assessment and Mitigation Phase (2019 – Pending)

SDG&E's second RAMP report is due on November 30, 2019.

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[5] https://www.sdge.com/sites/default/files/regulatory/R.18-10-007%20SDG%26E%20Wildfire%20Mitigation%20Plan.pdf

II. CONCLUSION

SDG&E herein submits its vulnerability assessments including documents that assessed how the utility may adapt to climate change in the future.

Respectfully submitted,

By: *<u>/s/ Christopher M. Lyons</u>*

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November 25, 2019

Climate Change and the Energy Sector

San Diego Gas & Electric

Regional Energy Sector Vulnerabilities and Resilience Strategies

Partnership for Energy Sector Climate Resilience

Part I. Vulnerability Assessment

February 2016

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Introduction

The Southwestern United States is characterized by mild coastal climates, arid inland regions, and mountain ranges that store critical water supplies to feed the growing population through the dry summer months. Historically, this area has been prone to many weather-related impacts that are projected to continue and intensify in the future, including:

- Increasing temperatures.
- Increased susceptibility to drought due to less frequent storm activity.
- Heavier rainfall in storms that do occur.
- Longer and more severe fire seasons.
- Rising sea levels.

These factors, which are discussed in greater detail below, are projected to have large impacts on the population, including the energy sector. Weather conditions have been noted to play a significant role in the safe and reliable delivery of gas and electricity to customers. As the climate evolves, the changes in temperature, rainfall patterns, wildfire frequency, and sea level rise will bring new challenges to the energy sector that may expose vulnerabilities unseen in past decades. The sections to follow will discuss the projected impacts of climate change on the San Diego region and will identify potential vulnerabilities in the generation and delivery of gas and electricity as described by the Department of Energy (DOE), United States Environmental Protection Agency (EPA), and employees of San Diego Gas & Electric.

Background Information

According to the Intergovernmental Panel on Climate Change (IPCC), the leading international body for the assessment of climate change composed of thousands of scientists from around the world, concentrations of greenhouse gases in the atmosphere have reached levels that are unprecedented in at least the last 150 years, as shown in Figure 1. The concentrations of carbon dioxide, methane, and nitrous oxide have all increased since 1850, with the greatest growth in carbon dioxide emissions recorded in the last 40 years. While oceans and soils have been noted to absorb some of these emissions, around 40% of the carbon dioxide released through human production is estimated to linger in the atmosphere despite a growing number of mitigation policies across the globe. The IPCC states that it is extremely likely that these emissions, in addition to other anthropogenic, or man-made, causes including urbanization of land, have contributed to more than 50% of the observed increases in global temperatures over the period 1951-2010 (IPCC 2014).

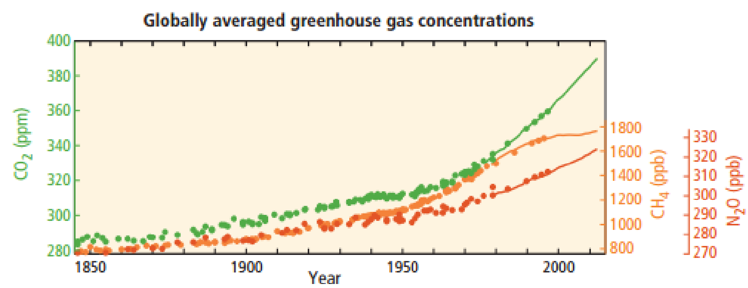

Figure 1. Atmospheric concentrations of the greenhouse gases carbon dioxide (green), methane (orange), and nitrous oxide (red) as determined from ice core data (dots) and direct atmospheric measurements (lines). Source: IPCC 2014.

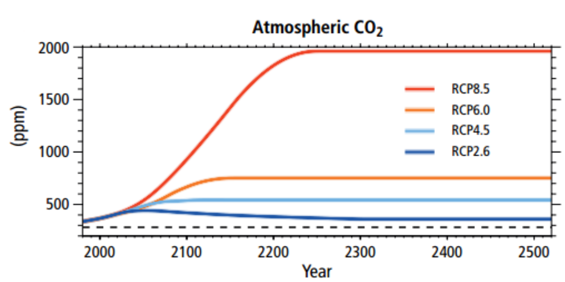

Figure 2. Carbon dioxide emissions scenarios (Representative Concentration Pathways; RPCs) defined by the IPCC, including a high emissions scenario (red), a low emissions scenario (dark blue), and two intermediate scenarios (orange, light blue). Source: IPCC 2014.

For the purposes of research and forecasting, the IPCC has compiled a series of anthropogenic emissions scenarios driven by population size, economic activity, lifestyle, energy use, land use patterns, technology, and climate policy. These scenarios are broken down into four basic types: one stringent scenario that assumes an eventual decrease in greenhouse gas emissions and keeps future global temperature increases below 3.6°F, one very high emissions scenario that reflects a fivefold increase in greenhouse gases by 2100, and two intermediate scenarios that fall in between the two extremes (IPCC 2014; see Figure 2 above). The results shown in the sections to follow use these four scenarios as a guide in the projected ranges of severity.

Temperature

Global temperatures in each of the last three decades have been successively warmer than any preceding decade since 1850 (IPCC 2014). According to data from the National Climate Data Center (NCDC), the 12-month mean of average temperatures along the Southern California coast has increased at a rate of 0.3°F per decade since the 1890s (see Figure 3), with the most recent year ending in July 2015 soaring to nearly five degrees above the climatic mean.

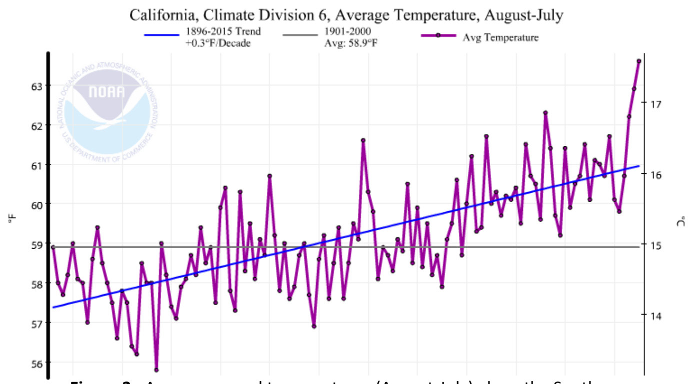

Figure 3. Average annual temperatures (August-July) along the Southern California coast from 1896-2015. Source: NOAA NCEI 2015.

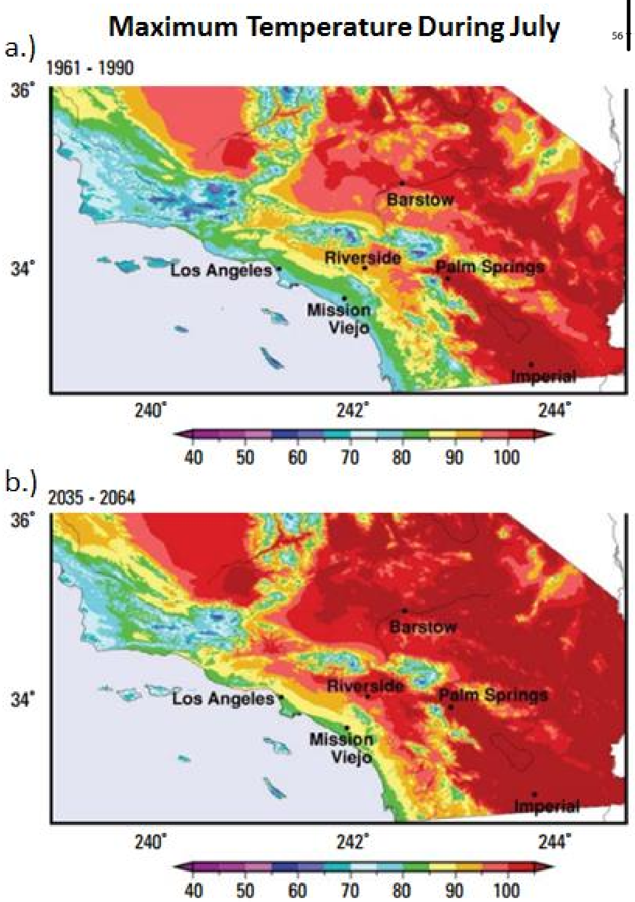

Figure 4. Average maximum July temperatures (a) observed in 1961-1990 baseline and (b) projected for 2035-2064. Source: Cayan 2009.

Confidence is high that temperatures will continue to increase through the next several decades. Most studies indicate that this warming will build over time with average temperatures increasing 2.5-5°F by 2050 and roughly 3-10°F by 2100, as shown in Table 1 below. Figure 4 shows that changes within the immediate coastal zones will be on the lower end of these scales due to their proximity to the ocean, which will be much slower to warm. Inland areas, particularly the foothills and mountains, are projected to experience more pronounced heat by the middle and end of the century (Cayan et al. 2013). Higher humidity across the San Diego region will lead to warmer overnight low temperatures, resulting in an increase in the overall average temperature year-round. However, impacts from heat and humidity are projected to be greatest in summer and fall (EPA 2015, Cayan et al. 2013, DOE 2015) with summertime heatwaves lasting up to two weeks longer than those in recent memory (USDA 2010, DOE 2015). Assuming the worst case emissions scenarios, it is also suggested that the conditions seen in what we currently consider to be the most significant heatwaves will increase in frequency and, by 2100, will become considered normal conditions for nearly a quarter of the year (USDA 2010).

A warming globe is also projected to lead to fewer cold snaps through the winter and spring (IPCC 2014, Cayan et al. 2013). The 21st century has already noted an increase in the number of freeze-free days across the Southwest compared to the 1901-2000 average, with 17 fewer days per year measuring temperatures below 32°F between 2001 and 2010 (Cayan et al. 2013). This number is projected to double by mid-century (Cayan et al. 2013).

	2050	2100
Temperature/Heat Wave Projections		
• San Diego Foundation/SCRIPPS	• +3.1°F average temperature rise in San Diego, 7 times as many days of extreme heat per year	• +3-10.5°F with 2-4 times as many heat waves
• DOE	• 10-25 more extremely hot days per year, especially inland	• +3.5-8.5°F in Southwest
• EPA	• +2.5-5.5°F in Southwest	• +3.8-10.2°F in Southwest
• USGCRP	• +2.6-5.5°F in Southwest	• +3.8-10.2°F in Southwest

Table 1. Compilation of temperature and heat wave projections from multiple sources for both 2050 and 2100.

Temperature: Potential Vulnerabilities

As temperatures rise, demand for energy to cool homes and businesses will likely follow suit, resulting in increases in peak electricity demand during the hotter summer months. Though the growing renewable energy market in the San Diego Gas & Electric service territory may help to dampen some of the impacts from the increased need for electricity, peak solar and wind generation occur at times that are offset from the daily peak in energy demand across the region. To make up for the difference, gas-fired generation would be needed on many days. This link would result in an increased demand for gas resources as well, potentially putting additional stresses on regional gas systems during prolonged heat waves (Kohls 2015).

Projections for increased humidity and warmer overnight temperatures would bolster the need for energy resources, but may also introduce issues with efficiency, capacity, and infrastructure lifetimes. The cooler nights tied to our current climate are necessary, particularly during the summer, to allow the electric infrastructure to cool and recycle itself. Increasing overnight temperatures would derail this process which, when met with the impacts driven by hot daytime temperatures, may lead to less efficient power production and reduced substation capacity (DeJulio 2015). Many transformers also house insulation that breaks down at accelerated rates under hot conditions. This factor, as well as the potential for transformer overloading during heat waves, may contribute to rapid shortening in the lifespan of transformers during the longer stretches of hot days and warm nights (DeJulio 2015). More persistent heat may also lead to thermal expansion of the electric infrastructure, triggering the potential for sagging transmission lines that could lead to damages and a higher number of outages (DOE 2015).

Other factors to consider as temperatures rise will be revisions of current company policies and the need to adapt to evolving regulations and standards set by government entities and the California Public Utilities Commission. Specific to San Diego Gas & Electric, planned outage programs to perform necessary work and infrastructure upgrades may become susceptible to more frequent cancellations during the summer months to avoid putting customers at risk without access to air conditioning and other cooling mechanisms during heat waves (Jones 2015). Statewide emissions regulations and restrictions on water use may also impact the availability of power imports during the hotter summer months (DOE 2015).

Drought and Rainfall Patterns

The current highly-publicized California drought has been one for the record books. Though this dry stretch is documented to have begun in 2012, the 2001-2010 decade was the warmest and fourth driest on record for the Southwest region dating back to 1900, and the current 2011-2020 decade is on track to be even warmer and drier. Since the start of 2015 alone, California has experienced the fourth driest January-February-March period on record and has shattered records for the lowest Sierra snowpack with snow water levels of only five percent of the historical average on April 1. However, portions of the state have also broken significant rainfall records this year, including in the San Diego region where the second wettest May in 140 years of record keeping was documented

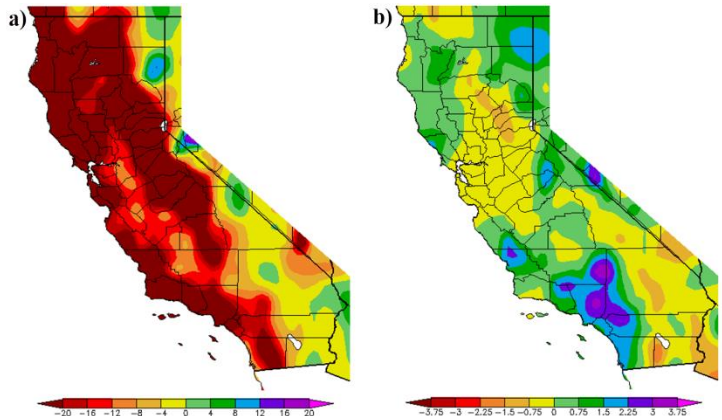

Figure 5. Precipitation departure from average in inches for (a) September 2012 through September 2015. (b) Summer 2015. Source: NOAA Western Region Climate Center.

	2050	2100
Rainfall Pattern Projections		
• San Diego Foundation/SCRIPPS	• 8% more rainfall during large storms, 16% fewer rainy days	• 10-20% more intense rainfall
• DOE	• Number of days of <0.03mm rain will increase by 5-25 per year	• 3-12% less precipitation
• EPA	• N/A	• 15-35% less precipitation
• USGCRP	• Up to 16% more rain in winter, but as much as a 22% decline in summer rainfall	• Up to 23% increase in winter precip, but up to 24% decline in summer rainfall
Drought Projections		
• San Diego Foundation/SCRIPPS	• 12% decrease in runoff and streamflow	• 50-75% loss of April 1 snowpack and 1.5-2.5 times more critically dry years
• DOE	• N/A	• Snowpack decrease of up to 43% in California
• USGCRP	• Water volume reduction of up to 34% in Sierra snowpack	• Water volume reduction of up to 57% in Sierra snowpack

Table 2. Compilation of rainfall pattern and drought projections from multiple sources for both 2050 and 2100.

and the measured 1.71 inches of rain in July equaled an accumulation greater than that of the past 100 Julys combined.

According to researchers, trends such as these will become more common across the Southwest into the next century (see Table 2). While many projections include more intense precipitation events with as much as 10-20% more rainfall from individual storms, storm activity is also forecast to become less frequent, leading to an overall decline in annual rainfall for the region (IPCC 2014, Cayan et al. 2010, McAfee et al. 2011, Cayan et al. 2013). The largest shortfalls are predicted to come during the winter months when more than 50% of the annual precipitation typically falls in Southern California. Due to the increasing temperatures discussed above, storms that do occur will be warmer, leading to higher snow levels that will, when combined with the projected shortfalls in annual precipitation, result in an overall reduction in the Sierra snowpack that may fuel prolonged periods of drought across the state. In fact, several projections call for a significant increase in the number and duration of extreme drought events from 2050-2100 with the most severe dry spells extending beyond 5 years and, in the most extreme cases, persisting for more than a decade (Cayan et al. 2010).

More uncertainty exists in predictions of the summer monsoon and tropical activity in the Southwest. The year-to-year variability in summer precipitation generated by these events is dependent on many large and smaller scale processes, including sea surface temperature patterns (i.e. El Niño/La Niña), topography, and daily weather features. However, the global climate models focus on broader scale features and are unable to fully resolve the regional day-to-day processes (Cayan et al. 2013). In addition, more research is needed to be able to fully understand and predict El Niño and La Niña episodes and their influence on the monsoon.

Drought and Rainfall Patterns: Potential Vulnerabilities

The more intuitive impacts from more severe and longer lasting droughts include less water available for cooling of the electric equipment, which would eventually have impacts on generator efficiency, and limited availability of water resources for the ongoing major projects and construction (DeJulio 2015). However, extensive drought conditions would also impact the underground gas pipelines in the region. Corrosion of the gas lines is prevented through cathodic protection. In this process, a small charge is introduced to the pipeline and the water in the soil acts as a current conducting material. Without the water to complete the circuit, the cathodic protection is lost and the pipelines become more susceptible to corrosion, thus potentially shortening the lifespan of the gas infrastructure (Kohls 2015). A lack of groundwater in our most recent drought has also caused subsidence of the land in some parts of the state. If drought conditions worsen as projected, subsidence in dry areas may eventually damage pipelines used for import into the San Diego region that would reduce the availability of gas products (Kohls 2015).

Damages may also be incurred on gas and electric infrastructure during heavy precipitation events. When combined with the complex topography across the San Diego Gas & Electric service territory, fast accumulations of heavy rainfall can lead to mudslides and landslides that can scour the soil and potentially expose or damage the gas and electric infrastructure (DOE 2015, Kohls 2015). The increase in heavy rainfall events may also lead to inundation that could produce underground electric outages, while runoff and localized flooding may lead to erosion around electric infrastructure (DeJulio 2015). Also, changes to the frequency and severity of the storms may result in delays in the repair and maintenance of the infrastructure, leaving customers susceptible to longer outages (DeJulio 2015).

Wildfire

Between January 1st and December 1st of 2015, 6,227 fires were reported across the state of California with a burn area totaling 307,592 acres. This was an increase of 1,985 fires and 116,321 acres burned during the same period in 2014, and stands at 140% and 281% of the 5-year averages of fires and acres burned, respectively (CAL FIRE 2015). While these numbers are exacerbated by the current four-year stretch of drought conditions, data ranging back to 1984 across San Diego County confirms that the number of high fire potential days each year has increased since the early 2000s (see Figure 6). These trends are projected to continue as a combination of factors leads to increases in both fire season duration and severity through the end of the century (Melillo 2014, Kent 2015, CEP 2014).

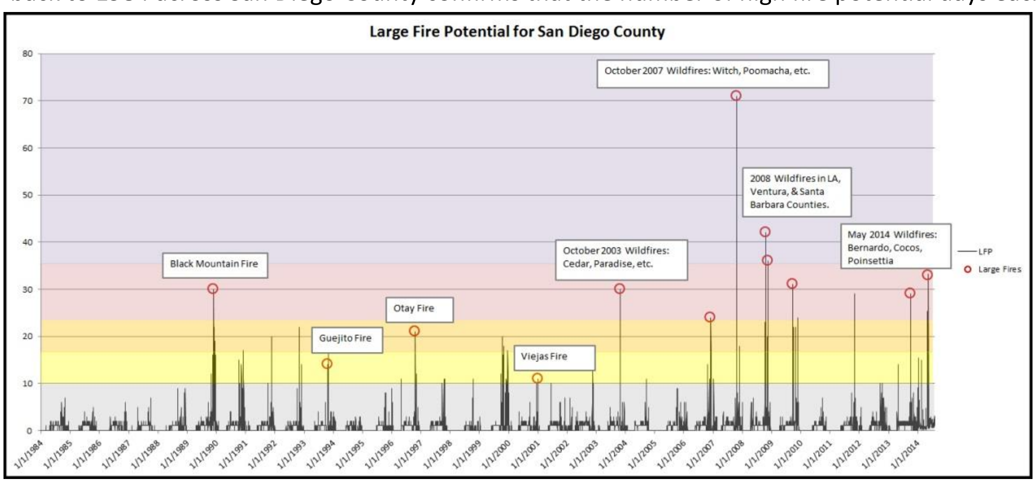

Figure 6. Large fire potential for San Diego County, calculated using a combination of weather and fuels conditions. Larger values indicate higher fire potential. Labels and red circles indicate observed large fires in San Diego County.

A 2013 study done by the National Oceanic and Atmospheric Administration (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS) group found that the effects of climate change will not significantly alter the frequency of Santa Ana wind events, which typically occur 2-5 days per month between October and March and have contributed to the growth of several of the largest fires in Southern California history. However, due to overall warming across the region, Santa Ana winds are likely to bring higher temperatures and lower humidity that will increase the fire potential with each event (Kunkel et al. 2013). Because Santa Ana wind events typically deliver the warmest conditions to the coastal communities, increases in fire potential may also extend to the coastal canyons and wildland areas that historically have not been as high of a wildfire concern. The warmer temperatures are also expected to enhance evaporation and transpiration even outside of Santa Ana events, which will deplete fuel moistures at faster rates. When coupled with longer dry periods, increases in tree mortality due to drought, and increased warmth, this will result in longer fire seasons across the Southwest (Kent 2015, Westerling et al. 2006).

Though the general consensus is that fire seasons will lengthen and become more severe through the coming century, there are still several unknowns that may alter fire behavior including shifts in vegetation type and the rebound rates of fuels in burned areas (Kent 2015, Westerling et al. 2006). It has been suggested that some vegetation types will be unable to adapt to the temperature increases, which would initially lead to an ample supply of dead fuels to carry fire, but would eventually result in a decline in fuels coverage unless the vegetation was phased out by species more apt to handle the hotter temperatures (Kent 2015). In addition, assuming the fires fully consume the fuels, increases in fire activity will eventually become limited until enough vegetation can grow back to support fire growth (Kent 2015).

	2050	2100
Wildfire Projections • San Diego Foundation/SCRIPPS	• Longer and more extreme fire seasons	• Probability of large fires in SoCal could increase by 30%

Table 3. Wildfire projections for both 2050 and 2100. Many studies did not focus on wildfire impacts specific to Southern California and, thus, were not included.

Wildfire: Potential Vulnerabilities

Wildfire has been identified as one of the greatest weather-related risks to San Diego Gas & Electric, due to the region's complex topography, lack of summer and early fall rains, and susceptibility to dry Santa Ana winds that can accelerate fire growth. It was this combination of factors that led to the Cedar Fire of 2003 and the Witch Fire of 2007 – both of which rank among the top 10 largest wildfires in California history – that spread across San Diego County and had large impacts to the utility. Because of the known wildfire risk and the potential impacts on utility operations, SDG&E has identified the locations at greatest risk for fire growth within the service territory and instituted a process to make the electric system more resilient to wildfires that includes replacing wooden poles with steel, installing new technologies to make the electric grid more resilient to fire and building upon a robust vegetation management program to keep trees and brush clear of power lines.

Despite the proactive approach to mitigating fire risk, increases in temperature and prolonged periods of drought in the decades to come will likely lead to high risk fire areas expanding from the foothills and mountains into the lower elevation coastal canyons and wildland interfaces that were previously considered at lower risk for fire growth. This would result in the potential for more damaged or destroyed wooden poles with any fires that occur and may even cause household impacts if the fires run up the canyons into densely populated neighborhoods (Kohls 2015). Projections for longer fire seasons also bring the potential for an increased number of planned work cancellations due to high fire concerns, including government-issued restrictions in national forestland.

Sea Level Rise

Oceans cover roughly two-thirds of the globe and play a large role in regulating the earth's temperatures. Recent studies have shown that the oceans are also absorbing 90% of the heat trapped by greenhouse gases in the atmosphere (Melillo et al. 2014). As the water warms, it expands in a process called thermal expansion, resulting in sea level rise for coastal communities. Sea levels are also impacted by the melting of glaciers and ice sheets as global temperatures rise (Melillo et al. 2014, IPCC 2014). Data from tide gauges around the world show that the average global sea level has risen 7-8 inches over the past century

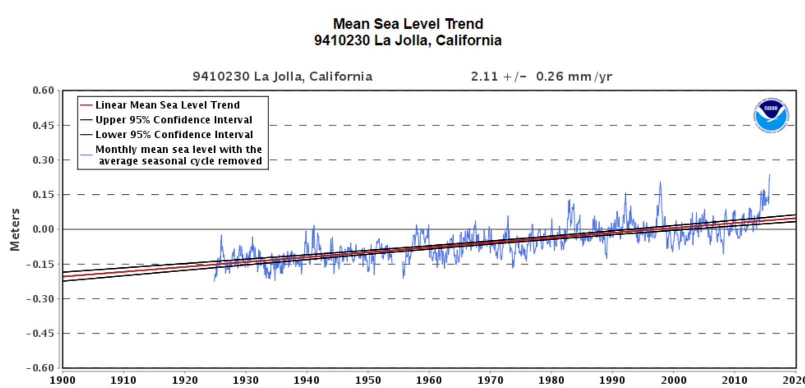

Figure 7. Measured monthly mean sea level at Scripps Pier with the normal seasonal cycle removed. Source: NOAA 2013.

(IPCC 2014). However, since measured increases at individual tide gauges are largely dependent on the surface wind direction, location of the warmer water and the direction of the currents carrying the melted ice, sea level rise has not been uniform around the world. Local data from Scripps Pier shown in Figure 7 above indicates that water levels have risen 8.28 inches in the past 100 years with an average increase of 2.11 millimeters per year (NOAA 2013). This is consistent with the eight inch rise in sea level in the last century reported at the San Francisco tide gauge (CCC 2015).

Uncertainties in the levels of greenhouse gas emissions and their impacts on global temperatures through the next century lead to wide ranges of potential sea level rise scenarios. The general consensus is that by 2050 the California coast will see a rise of as few as five inches, assuming a low emissions scenario, to as high as two feet (see Table 4 below) when compared to the similar base state sea levels of 1990 and 2000. Assuming the worst case scenario of two feet, mapping resources indicate that shallow water would cover portions of Imperial Beach and Border Field State Park while low lying areas of the Del Mar Fairgrounds would see some inundation from a daily high tide, as seen in Figure 8a and 8b, respectively. These impacts would be exacerbated by storm surge and King Tides, which would draw water further inland and worsen coastal erosion (Porter et al. 2011). In addition, thermal expansion of the water during strong El Niño events has been known to increase local sea levels, as shown in Figure 7 by spikes in the Scripps Pier mean sea level in 1982-83, 1997-98, and 2015, which may also add to the coastal impacts when such events occur in the future.

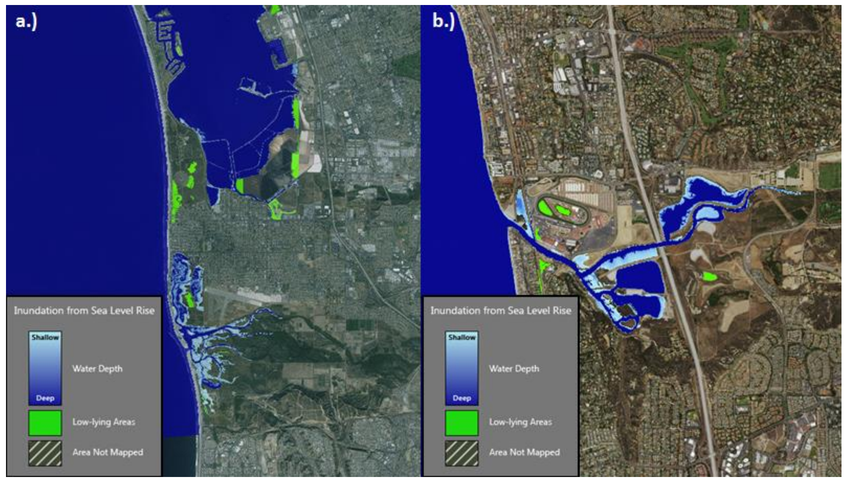

Figure 8. Projections of two feet of sea level rise at (a) Imperial Beach and Border Field State Park and (b) Del Mar Fairgrounds. Projections are base state and do not include inundation due to high tide or storm surge. Source: NOAA 2015.

Uncertainty is high in projections for 2100, when the range of sea level rise possibilities extends from increases of six to 79 inches (see Table 4 below) depending on the emissions scenario. Recent studies indicate that using the lowest emissions scenarios, melting small mountain glaciers, and accounting for thermal expansion of the oceans results in 11 inches of global sea level rise without taking into account the melting of the Greenland and Antarctica ice sheets (Melillo et al. 2014). Therefore, these studies suggest that the lowest reasonable estimate will be one foot of global sea level rise by 2100. As discussed before, this will not be a uniform rise around the world, though it is suggested that about 70% of coastlines will experience sea level change within ±20% of the global mean (IPCC 2014). The greatest impacts to this rise will, again, be witnessed during high tides and storm events.

	2050	**2100**	**Comments**
Sea Level Rise Projections			
• San Diego Foundation/SCRIPPS	• 5-24 inches	• 6-30 inches	Relative to 2000 sea level
• DOE	• N/A	• 17-66 inches	Relative to 2000 sea level
• EPA	• 10-22 inches	• 30-74 inches	Relative to 1990 sea level
• USGCRP	• N/A	• 7-79 inches	Relative to 1990 sea level
• NRC	• 5-24 inches	• 16-66 inches	Relative to 2000 sea level
• IPCC	• N/A	• 15-28 inches	Relative to 1985-2005 baseline

Table 4. Compilation of sea level rise projections for the Southern California coast from multiple sources for both 2050 and 2100.

Sea Level Rise: Potential Vulnerabilities

The San Diego Gas & Electric service territory spans more than 80 miles of coastline that, according to the projections outlined above, will become susceptible to the rising oceans in the years to come. While research of increasing sea levels has been included in the planning process for new coastal facilities, including the South Bay Substation along the San Diego Bay that was built as high as 21 feet above sea level in some areas to account for the rising seas, low-lying substations and underground facilities built before sea level rise specifications were taken into account would remain at risk of flooding, particularly during storm surges and high astronomical tides (DeJulio 2015). These areas would become more susceptible to outages due to flooding, and accessibility issues caused by the inundation may result in crews being unable to make quick repairs, leading to the potential for prolonged outages (DeJulio 2015). Similar issues arise with the underground gas facilities in coastal regions that the rising sea levels may eventually completely cover. Additional concerns are that the inundation of salt water will increase corrosion of the gas pipelines that run parallel to the coast (Kohls 2015).

References

CAL FIRE (California Department of Forestry and Fire Protection), 2015. Incident Information: Number of Fires and Acres. Accessed August 24. http://cdfdata.fire.ca.gov/incidents/incidents_stats?year=2015.

Cayan, D., 2009. "Climate Change – What Should Southern California Prepare For?" in *Climate Change and the Future of Southern California:* 10-21 pp.

Cayan, D., T. Das, D.W. Pierce, T.P. Barnett, M. Tyree, and A. Gershunov, 2010. *Future Dryness in the Southwest US and the Hydrology of the Early 21st Century Drought*. Proceedings of the National Academy of Sciences 107(50): 21271-21276.

Cayan, D., M. Tyree, K.E. Kunkel, C. Castro, A. Gershunov, J. Barsugli, A.J. Ray, J. Overpeck, M. Anderson, J. Russell, B. Rajagopalan, I. Rangwala, and P. Duffy, 2013. "Future Climate: Projected Average." In *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment,* edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. Leroy, 101-125. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

CCC (California Coastal Commission), 2015. *California Coastal Commission Sea Level Rise Policy Guidance: Interpretive Guidelines for Addressing Sea Level Rise in Local Coastal Programs and Coastal Development Permits.* 291 pp. 31 July 2015.

CEP (Climate Education Partners), 2014. *San Diego, 2050 is Calling.* Accessed August 10. http://www.sandiego.edu/2050/

DeJulio, Maurizio. Personal communication. 21 October 2015.

EPA (Environmental Protection Agency), 2015. *Climate Impacts in the Southwest.* Accessed August 24. Updated 21 July 2015. http://www3.epa.gov/climatechange/impacts/southwest.html

IPCC, 2014. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Jones, Melissa. Personal Communication. 6 October 2015.

Kent, L.Y., 2015. *Climate Change and Fire in the Southwest.* ERI Working Paper No. 34. Ecological Restoration Institute and Southwest Fire Science Consortium, Northern Arizona University: Flagstaff, AZ. 6 pp. http://swfireconsortium.org/wp-content/uploads/2015/06/Yocom_Climate_Fire_SW.pdf

Kohls, Norm. Personal Communication. 6 October 2015.

Kunkel, K.E., L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, K.T. Redmond, and J.G. Dobson, 2013. *Regional Climate Trends and Scenarios for the U.S. National Climate Assessment*. Part 5. Climate of the Southwest U.S., NOAA Technical Report NESDIS 142-5, 79 pp.

McAfee, S.A., J.L. Russell, P.J. Goodman, 2011. *Evaluating IPCC AR4 Cool-Season Precipitation Simulations and Projections for Impacts Assessment over North America*. Climate Dynamics 37: 2271-2287.

Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014. *Climate Change Impacts in the United States: The Third National Climate Assessment.* U.S. Global Change Research Program, 841 pp. doi:10.930/J0Z31WJ2

NRC (National Research Council), 2012. *Sea-Level Rise for the Coasts of California, Oregon and Washington: Past, Present, and Future.* Washington, DC: The National Academies Press, 2012. http://nas-sites.org/americasclimatechoices/sea-level-rise/

NOAA (National Oceanic and Atmospheric Administration), 2013. "Tides & Currents." Accessed August 12, 2015. http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=9410230

NOAA, 2015. "U.S. Climate Resilience Toolkit." Accessed August 14, 2015. http://toolkit.climate.gov/

NOAA NCEI (National Centers for Environmental Information), 2015. "Climate at a Glance." Accessed August 20, 2015. http://www.ncdc.noaa.gov/cag/time-series/us

Porter, Keith, et al., 2011. *Overview of the ARkStorm scenario: U.S. Geological Survey Open-File Report 010-1312,* 183 pp. and appendices. http://pubs.usgs.gov/of/2010/1312/

PPIC (Public Policy Institute of California), 2008. *Adaptation of California's Electricity Sector to Climate Change.* San Francisco, CA: Public Policy Institute of California. http://www.ppic.org/content/pubs/report/R_1108EVR.pdf.

SDG&E (San Diego Gas & Electric), 2007. "SDG&E expects 97 percent of fire-impacted customers restored by Nov. 4." Oct. 27, 2007. http://www.sdge.com/newsroom/press-releases/2007-10-27/sdge-expects-97-percent-fire-impacted-customers-restored-nov-4.

USDA (United States Department of Agriculture), 2010. *Southwest Region Climate Change Trends and Forest Planning: A Guide for Addressing Climate Change in Forest Plan Revisions for Southwestern National Forests and National Grasslands.* Accessed August 26, 2015. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5284414.pdf

US DOE (United States Department of Energy), 2015. *Climate Change and the U.S. Energy Sector: Regional Vulnerabilities and Resilience Solutions.* October 2015. http://energy.gov/sites/prod/files/2015/10/f27/Regional_Climate_Vulnerabilities_and_Resilience_Solutions_0.pdf

Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam, 2006. *Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity.* Science, Vol. 313 no. 5789, pp. 940-943. doi:10.1126/science.1128834

Williams, A.P., R. Seager, J.T. Abatzoglou, B.I. Cook, J.E. Smerdon, and E.R. Cook, 2015. *Contribution of Anthropogenic Warming to California Drought during 2012-2014.* Geophysical Research Letter, 42, 6819-6828, doi:10.1002/2015GL064924.

Climate Change and the Energy Sector

SDGE

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Regional Energy Sector Vulnerabilities and Resilience Strategies

Partnership for Energy Sector Climate Resilience

Part II. Climate Resilience Plan

November 2016

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Introduction

The increasing occurrence of significant weather events across the globe has become more evident in recent years. The changing climate and resulting potential for extreme weather events has led to the need for assessments to determine the regional level of impacts on utilities and their customers due to the increasing prevalence of severe droughts, wildfires, extreme heat, rising sea levels, and more. Through these assessments, plans can be created and implemented to minimize the impacts of severe weather on our nation's energy infrastructure.

According to many scientists, climate change projections for the San Diego region highlight several potential impacts, including:

- Longer and more severe fire seasons
- Rising sea levels and increased storm surge
- Increased susceptibility to drought due to less frequent storm activity
- Heavier rainfall in storms that do occur
- Rising temperatures and extreme heat events.

Wildfire has been identified as the greatest weather-related risk to SDG&E, due to the region's complex topography, lack of summer and early fall rains, and susceptibility to dry Santa Ana winds that can accelerate fire growth. System hardening efforts to build resiliency to wildfires into the electric grid began after large wildfires fueled by strong Santa Ana winds and dry vegetation swept through the SDG&E service territory in 2003 and again in 2007. These efforts, which continue today, are projected to continue in the years to come.

Plans to improve resiliency in the face of additional climate change impacts are being undertaken by SDG&E. The first step, a vulnerability report outlining in detail the future climate change projections for the SDG&E service territory, was submitted to the Department of Energy in February of 2016. The chapters to follow will use the understanding gained from the vulnerability report and apply this knowledge to resilience measures being adopted by the company as it strives to build a system more hardened to the occurrence of climate and severe weather-related hazards to come.

Prioritization of Resilience Measures

I. Establishing Climate Change Adaptation Priorities

San Diego Gas and Electric (SDG&E) has established climate change adaptation prioritization through the integration of climate risks into the preexisting enterprise risk structure. The Enterprise Risk Management (ERM) group at SDG&E has decided to leverage in-house subject matter expertise to cross reference the SDG&E Climate Vulnerability report with the company's risk registry who made the determination that Climate Change Impacts will impact many areas of the company in the coming decades. The focus of the analysis was to identify company assets or operations that are sensitive to climate risks as determined by the current state of the science. These criteria have led ERM to identify the following parent risks listed below as focus areas for continued climate risk investigation moving forward:

Wildfires:

- Potential climate triggers:
    - Increased fire risk to coastal canyons/wildland interfaces
        - Potential for damaged/destroyed wooden poles
        - Potential for distribution impacts of household electricity and gas
    - Increased number of planned work cancellations due to high fire concerns
        - Includes government-issued restrictions in national forestland
    - Increasing frequency of drought resulting in longer wildfire seasons
        - Potential for changing regulation
        - Potential for impacts to job scheduling due to extreme fire potential in the spring

Insufficient Natural Gas Supply to San Diego Transmission System:

- Potential climate triggers:
    - Increases in extreme heat waves
    - Increases in average temperatures
    - Warmer overnight temperatures

Increased Electric Rates/Flawed Electric Rate Design:

- Potential climate triggers:
    - Increases in extreme heat waves
    - Increases in average temperatures
    - Warmer overnight temperatures

Electric Infrastructure Integrity:

- Potential climate triggers:
    - Increased fire risk region-wide, including coastal canyons/wildland interfaces
        - Potential for damaged/destroyed wooden poles
        - Potential for distribution impacts of household electricity and gas
    - Changes in rainfall patterns are projected to lead to increased susceptibility of flooding of low-lying substations and underground infrastructure
        - Higher intensity rainfall rates may also lead to storm water run-off and soil erosion, potentially damaging infrastructure in areas prone to these events
    - Projected sea level rise, in conjunction with high storm surge, may lead to inundation of low-lying substations, inundation of underground facilities, and/or delays in repairs and maintenance at levels unseen in the past
    - Increases in temperature may lead to stresses and decrease the useful life of current infrastructure
        - Increases in extreme heat waves
        - Increases in average temperatures
        - Warmer overnight temperatures

IT Infrastructure Risk (Natural Disasters):

- Potential climate triggers:
  - Increased fire risk region-wide, including coastal canyons/wildland interfaces
  - Changes in rainfall patterns and sea level rise will lead to increased flooding potential territory-wide
  - Less frequent, but more intense winter storms are expected to increase the high wind threat in the future

Insurance Coverage Issue:

- Potential climate triggers:
  - Increased fire risk region-wide, including coastal canyons/wildland interfaces: Increased potential for May 2014 type events in the future
  - Increased wildfire activity statewide may impact San Diego
  - Projected sea level rise, in conjunction with high storm surge, may lead to inundation of low-lying substations, inundation of underground facilities, and/or delays in repairs and maintenance at levels unseen in the past which could impact insurance coverage.

Catastrophic Damage Involving Medium and non-DOT Pipeline Failure:

- Potential climate triggers:
  - Increased susceptibility to drought may decrease effectiveness of cathodic protection on pipelines
  - Change in rainfall patterns will make areas prone to soil erosion more at-risk in the future
  - Increase in wildfire risk to coastal canyons/wildland interfaces
  - Increased susceptibility to corrosion of underground pipelines due to sea level rise and inundation in locations unseen in the past

Management of Emergency Spares for Major Electric Equipment:

- Potential climate triggers:
  - Increases in temperature may lead to system stresses on current infrastructure
    - Increases in extreme heat waves
    - Increases in average temperatures
    - Warmer overnight temperatures
  - Projected sea level rise, in conjunction with high storm surge, may lead to inundation of low-lying substations and inundation of underground facilities at levels unseen in the past
  - Increased fire risk region-wide, including coastal canyons/wildland interfaces: Increased potential for May 2014 type events in the future
    - Potential for damaged/destroyed wooden poles
  - Changes in rainfall patterns are projected to lead to increased susceptibility of flooding of low-lying substations and underground infrastructure
    - Higher intensity rainfall rates may also lead to mudslides and landslides, potentially damaging infrastructure in areas prone to these events

Impact of Unplanned Outages at Utility Owned Generation Plants:

- Potential climate triggers:
  - Increased fire risk region-wide, including coastal canyons/wildland interfaces

Failure of Disaster Recovery/Business Resumption Plans:

- Potential climate triggers:
  - Increased fire risk region-wide, including coastal canyons/wildland interfaces
  - Changes in rainfall patterns may increase susceptibility of flooding at some facilities

Each of the parent risks, including their climate component, are then analyzed and prioritized leveraging the six-step risk management process consistent with ISO 31000 (see Figure 1). As part of this process, each of the risk that are identified above, including all other enterprise risks for SDG&E are then analyzed closely looking at a 7X7 matrix, focusing on the following impacts: Health, Safety and Environmental; Operational and Reliability; regulatory, Legal and Compliance; and Financial.

Figure 1. Six-step risk management process

After each of the parent risks have received their primary ratings, these are then fit into an algorithm listed and demonstrated below to identify which of these risk post the highest threat overall. This then enables the organization to prioritize risk mitigation measures.

For the climate change risk, the 7X7 matrix was used to determine the scores provided in Table 1:

Table 1. Frequency ratings for the climate change risk as defined by the 7X7 matrix.

Residual Impact				Residual Frequency	Residual Risk Score
Health, Safety, Environmental (40%)	Operational & Reliability (20%)	Regulatory, Legal, Compliance (20%)	Financial (20%)		
4	5	4	5	3	2,656

In determining the scores for this risk, SMEs identified the climate variables currently impacting the SDG&E service area, including wildfire. Research done by the Desert Research Institute indicates that 93% of San Diego residents polled from the wildland urban interfaces in San Diego County have been impacted by wildfire. Should a wildfire event take place, energy may be turned off for thousands of customers either because of damaged equipment or for safety reasons, at the request of fire agencies attempting to put out the fire. This may have impacts on medical baseline customers who rely on power for their medical equipment. In addition, wildfires can affect indoor air quality for nearby residents by spreading ash and smoke, leading to decreased lung function and respiratory problems, increasing the risk of burns and injury from debris, and increasing the risk of injury due to motor vehicle accidents caused by smoke-related low visibility. Furthermore, catastrophic wildfire would have significant but short-term impacts on the environment by spreading smoke and ash to nearby regions and burning vegetation in the immediate vicinity, which leads to a Health, Safety, & Environmental score of 4 (major).

The potential safety consequences of a changing climate are wide-reaching and include everything from long-term power outages to risks of wildfire, fast-moving floodwaters, and extreme heat. The long-term power outages would have the largest safety consequences on medical baseline customers, who require the use of powered medical devices. However, safety concerns would arise for all impacted customers in the event that the outages spanned a time of harsh weather conditions, including extreme heat or cold.

During the October 2007 wildfires that burned 13% of San Diego County, estimates were that full electric service restoration to all customers would take as long as 20 days. Based on this estimate, the Operational & Reliability impact area has been scored as a 5 (extensive).

Climate change is already being discussed by the California Public Utility Commission (CPUC) for regulatory consideration. In July of 2015, SDG&E executive leadership participated in a climate adaptation en banc hosted by the CPUC and highlighted the efforts of SDG&E in combatting the effects of climate change to build a more resilient electric system. The CPUC has also offered guidance to the major California utilities in responding to the projected impacts of climate change, urging them to develop inventories of affected assets and to identify and prioritize any vulnerabilities that may arise under a changing climate. For these reasons, it is believed that regulatory agencies will enact stricter climate policies in the future and produce updated regulations to ensure resilience of the electric system, resulting in this risk being scored a 4 (major) in the Regulatory, Legal, and Compliance impact area.

SMEs considered the cost of adaptation measures to mitigate damages due to climate-related disasters. In doing so, some of the largest adaptation projects across the country have been referenced, including SDG&E's Fire Risk Mitigation (FiRM) project. The FiRM project, which began in 2014, is a $1 billion initiative that replaces older overhead distribution lines in the areas deemed most at-risk for wildfires with stronger steel poles and additional technologies that will make the system more resilient to harsh weather conditions. Due to the high cost of such adaptation programs and the growing need to proactively build resiliency to weather-related hazards, a financial score of 5 (extensive) has been given to the Financial impact area.

The projected severity of climate-related disasters leads to the potential for long-term outages, which can result in increased liability. The widespread impacts possible climate-related events, including wildfire, can also lead to project delays and increased costs for construction and operations to repair or replace damaged infrastructure. In addition, with climate becoming an emerging political topic, increased regulatory consideration and development of stricter climate-related policies will be possible in the years to come.

SMEs have reviewed recent climate projections to determine that significant climate change impacts will slowly build over the next 10-30 years. For this reason, the frequency score has been listed as a 3 (infrequent).

Frequency rating	Value (annual)
1	0.006
2	0.018
3	0.058
4	0.183
5	0.577
6	3.162
7	31.62

Table 2. Look-up table for frequency values.

Using the impact scores listed in Table 1 and cross-referencing them with Table 2 to find the frequency value, the risk score for climate change can be calculated by:

Sample Risk Score: = $\sum_{i=1}^{n} weight_i * frequency_i * 10^{impact_i}$

= 40%*0.183*10^4 [safety] + 20%*0.577*10^5 [reliability] + 20%*0.183*10^4 [compliance] + 20%*0.577*10^5 [financial]

= 732 [safety] + 11,540 [reliability] + 366 [compliance] + 11,540 [financial]

= 24,178

The risks that receive the highest risk score and pose the greatest threat, particularly those with an elevated safety impact rating, are then moved into a separate category and classified as part of the Risk Assessment Mitigation Phase (RAMP).

Using this process, SDG&E has prioritized the most significant risks that the company faces. Several of these are the parent risks for climate threats, including:

- Wildfires
  - Impacted by longer and more severe fire seasons
- Electric Infrastructure Integrity
  - Most significantly impacted by sea level rise
- Catastrophic Damage Involving Medium and non-DOT Pipeline Failure
  - Most significantly impacted by drought and rainfall pattern changes and increasing temperatures
- Catastrophic Damage Involving High and non-DOT Pipeline Failure.
  - Most significantly impacted by drought and rainfall pattern changes and increasing temperatures

The following sections of this report will discuss in greater detail the steps being planned and implemented to lessen the impacts of climate change across the different business units of SDG&E.

Resilience Plan for Wildfire

Wildfires swept through San Diego County in 2003 and again in 2007. As evidenced by the many programs employed since these fires, SDG&E has built a company-wide focus on addressing and minimizing wildfire-related risks to public health, safety and welfare. SDG&E's commitment to fire safety, prevention, mitigation, control, and recovery is a central tenet of its corporate culture and SDG&E has taken a leadership role in proactively addressing fire threats in the communities it serves and shares its personnel, resources, information, communications facilities, and/or fire-defense assets so as to enhance the capabilities of the local communities to defend against any repeats of catastrophic wildfire events experienced in Southern California.

The assessments and analyses provided in the following sections largely focus on wildfires within the SDG&E service territory. SDG&E strives to reduce or eliminate sources of ignition coming from its facilities, especially at times of peak weather where a small fire can turn into a large catastrophic event. The mitigation activities discussed herein, however, address and are applicable to all wildfires, including force of nature events.

I. Minimizing Sources of Ignition

The SDG&E Fire Prevention Plan is founded upon the goal of minimizing the probability that the various components of its sixty-nine kilovolt transmission and twelve kilovolt distribution system might become the original or contributing source of ignition for a fire. SDG&E evaluated the prudent, cost-effective changes and improvements to its physical assets that could and should be made in order to meet this objective and implemented preventative operations, construction and maintenance plan consistent with these evaluations.

A. Mapping the Fire Areas in the SDG&E Service Territory

SDG&E has performed and completed extensive mapping of its service territory to identify those areas at greatest risk to the occurrence of uncontrolled fires. Through these efforts, SDG&E identified two sets of geographic areas based on the potential risk of fire in the area and the threat to the public safety posed by fire. These two areas are known as the "Fire Threat Zone" (FTZ) and the "Highest Risk Fire Area" (HRFA). Generally, the FTZ includes the geographic areas most prone to wildfire due to local environmental conditions and features, and the HRFA includes areas within the FTZ where the risk of fire is the greatest.

1. Mapping the FTZ

SDG&E mapped its service territory to identify those areas where, due to local environmental conditions and features, the potential for wildfire was relatively high. This FTZ would be used to identify the areas where enhancements to rules, regulations and standards could reduce the potential for electric systems and facilities to ignite fires and thereby increase public safety and system reliability.

The FTZ mapping effort followed several key, objective principles. First, the FTZ was defined using parameters that would result in relatively constant boundaries not subject to continuous change and revision. This resulted in the use of criteria that tended to be conservative, i.e., more inclusive than exclusive, so that the FTZ would describe the complete domain where the potential for wildfire was relatively high. Additionally, the FTZ map would need to be easily understood by key personnel and users, whether utility or other public officials, who might rely upon it in performing their job responsibilities.

In performing the mapping task, SDG&E began with the vegetation data developed and maintained by the California Department of Forestry and Fire Protection (CAL FIRE). These data were available on the CAL FIRE Fire and Resource Assessment Program (FRAP) website. Using this data, SDG&E mapped the FTZ in its service territory. This zone encompasses most of the vegetated rural areas in San Diego and Orange Counties. Compared to the HRFA described below, the FTZ includes areas where the density of vegetation is relatively low. The FRAP maps describe the fire risks in certain areas as “little or no threat,” “moderate,” “high,” “very high,” and “extreme.” Generally, the FTZ includes all of the areas described in the FRAP maps as “extreme” and “very high” risk, and some portion of the areas described as “high” risk. In shaping the FTZ, SDG&E also applied its knowledge of its service area and internally developed high-resolution weather data and histories.

Because SDG&E personnel use the FTZ map for various purposes, it was important to make the FTZ map easy to use and understand. One particular adjustment made by SDG&E to the raw data upon which the map was based was to create a contiguous FTZ, rather than create a multitude of “pockets” of high risk. The original data created a mosaic of areas of varying degrees of risk – such a map would have been difficult to interpret and use. As an example, based purely on the raw weather and vegetation data, there would have been areas where the risk of fire would have been designated as “little or no threat,” “very high,” and “low” again along a one-mile stretch of road. Rather than include and parse anomalies, SDG&E adjusted the shape of the FTZ to normalize the design, construction, operations, maintenance, and inspection activities across larger areas. This resulted in the inclusion of some lower-risk areas in the FTZ and, in a few cases, the exclusion of some isolated higher-risk areas from the Threat Zone. The resulting FTZ is outlined in red in Figure 2 below.

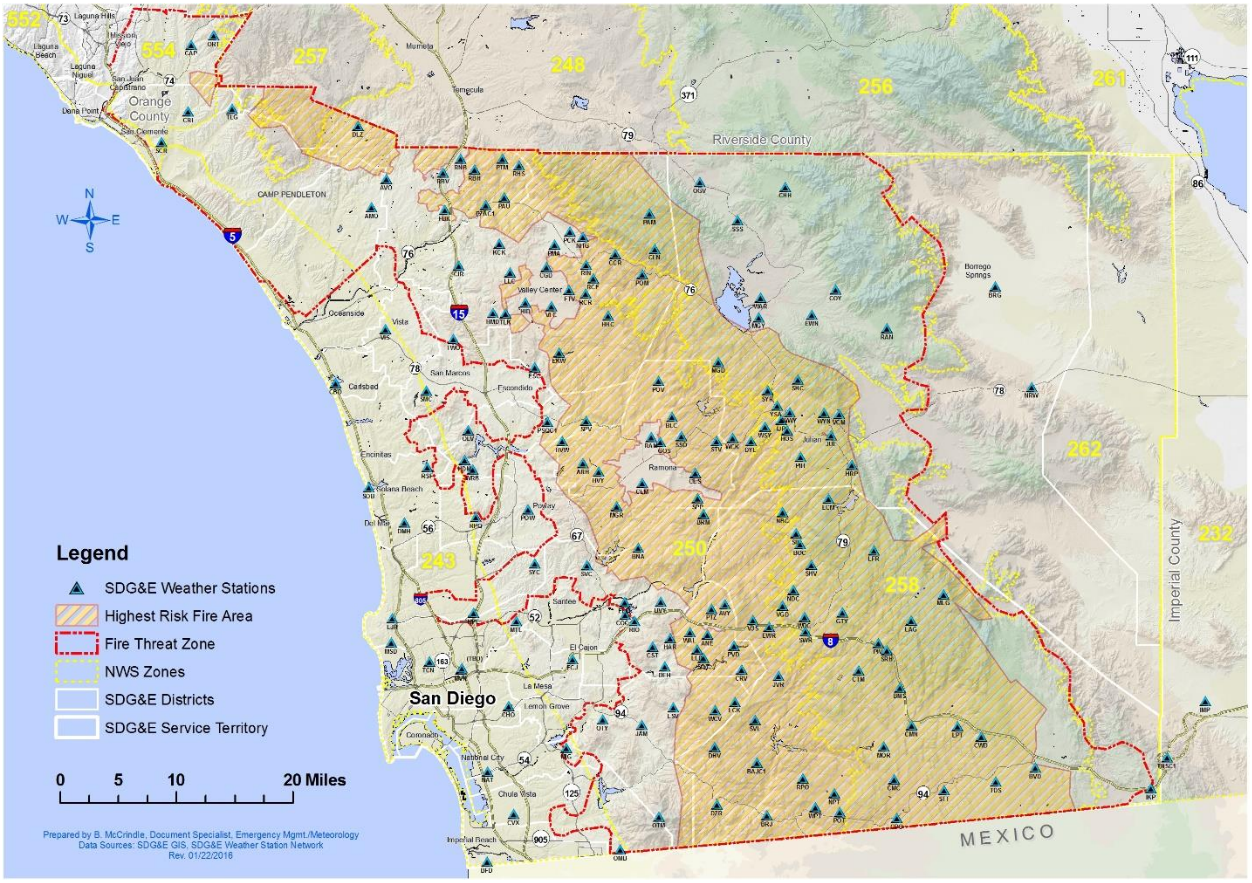

Figure 2. 2016 map of SDG&E FTZ, HRFA, and weather station network.

2. Mapping the HRFA

The HRFA represents those areas within the FTZ where local environmental conditions and features combine to create the highest risk of fire in the SDG&E service territory. SDG&E's Fire Coordinators, a team of in-house experts trained and experienced in fire behavior, fire prevention and firefighting, drafted the initial HRFA map in 2008 and reviewed annually (see Figure 2 for current map). Using Geographic Information System software, SDG&E's experts identified areas where the combination of relatively dense vegetation, relatively high winds, and development (*e.g.*, homes, hospitals, schools, and other community assets) presented the highest risks of fire, property losses and injury from fire. Thus, the HRFA map identifies the areas marked by an overlap of (1) the "highest risk vegetation", *i.e.*, where the vegetation was relatively dense and in close proximity to housing, business and/or community development,[1] and (2) locations prone to high winds.

As with the FTZ map, SDG&E utilized the FRAP data and maps available from CAL FIRE to determine the level of vegetation likely to exist in specific areas of the FTZ. Areas prone to high winds were identified using historical data from weather stations located throughout the SDG&E service territory. This included the use of data from SDG&E's private network of weather stations. The data were used to identify locations where there was a reasonable probability that wind speeds would exceed fifty miles-per-hour (50 mph) under the Santa Ana wind conditions

[1] In assessing fire risks and prioritizing fire prevention activities, SDG&E considers the potential that an uncontrolled fire will threaten members of the public and/or property. Based on expert analyses provided by the Fire Coordinator team, SDG&E considers the potential path a wildfire is likely to take and prioritizes its activities along those corridors where the risk to life and property are greatest.

usually experienced during the late summer and fall in Southern California. Finally, SDG&E adjusted the HRFA map to reflect our own knowledge and information regarding conditions in our service territory.

The HRFA maps are reviewed annually and adjusted to reflect environmental conditions expected to be present during the coming year's fire season, typically the late summer and fall seasons of each year. For example, fire perimeters and other fire protection measures are updated annually and reflected in the HRFA maps. In addition, the methodologies used to develop the HRFA map are reviewed and modified to ensure that lessons learned are incorporated into the map. As an example, SDG&E assures that the HRFA includes areas where there are data indicating a coincidence of high winds and dense vegetation.

B. Building Resiliency into the SDG&E System

SDG&E organizes its activities around addressing the threat of fire posed by various conditions and, in particular, on reducing the potential that SDG&E's facilities or operations might provide an original or contributing source of ignition for a fire. Forecasted and ambient wind conditions, especially when high winds combine with the hot, dry conditions typically experienced during the late summer and fall seasons in southern California, are an important factor in assessing and addressing fire threats.

Three-second gusts represent a "measurement standard" rather than an independent "fire condition." That is, the weather instruments relied upon by SDG&E for measuring wind conditions are designed and calibrated to measure, record and report wind speeds across ten-minute periods – the average of the wind speeds recorded across any single ten-minute period is reported as the "sustained wind." In computing wind data for each ten-minute period, wind speeds are measured across three-second intervals and the highest wind speed reached during any three-second interval within any ten-minute period is separately recorded as the highest "gust" for the period. With respect to assessing and responding to the potential threat of fires, SDG&E takes potential and actual wind speeds into account, both as to sustained winds and gusts. Although both sustained wind speeds and gusts are considered, SDG&E's Fire Prevention Plan programs and activities are not designed around either wind measure. Rather, both are considered within a full range of inputs related to Fire Prevention Plan programs and activities.[2] The three-second interval by which "gusts" are measured is not, then, an independent operational planning standard or the focus of facility design and construction standards. Thus, SDG&E closely monitors the current weather situation and adjusts its operation to take into account current wind speeds "that may exceed the structural or mechanical design standards for overhead power-line facilities," however SDG&E's safety-related activities cannot be said to address the potential for strong wind *gusts* as a stand-alone criterion.

Using the FTZ and HRFA maps, SDG&E evaluated the prudent and cost-effective system improvements it could make to its transmission and distribution system which would reduce the potential for SDG&E's facilities in the FTZ and HRFA to provide the source of ignition for a fire.

1. Design and Construction Standards

To reflect the more stringent design and construction standards adopted by the California Public Utility Commission and so as to improve the performance of the SDG&E system in terms of meeting fire-prevention goals, the SDG&E Facilities Design Manual was modified to include a section aimed at providing guidance for hardening circuits against the risk of fire. These modifications include both proactive measures designed to reduce the incidence of ignitions and reactive measures by which SDG&E can respond to the threat of fires and mitigate the threat of fires.

[2] As an example, among the non-environmental factors taken into account as SDG&E evaluates the threat of fire is whether firefighting assets are available or unavailable. Where local firefighting assets might have been previously deployed to a distant locale to fight an existing fire, SDG&E would be more conservative in assessing the actions it might take to abate or mitigate the potential threats within its service area. Winds would be a factor, but not the single determining factor under this circumstance, in deciding SDG&E's response to the local threat of fire.

SDG&E is also an aggressive advocate for modernizing those portions of the California Public Utility Commission's General Order 95, which provides the rules and regulations governing the design and construction of overhead electric and communications facilities. Fire safety begins with the design and construction standards pursuant to which utility facilities are designed, built and operated, so improving these regulations will provide the foundation for assuring that facilities built in the future will be stronger and safer than those built under prior versions of the rules.

2. Wood-to-Steel Program

Of significance is SDG&E's program to undertake replacement of wood poles used in those portions of the SDG&E sixty-nine (69) kilovolt transmission and twelve (12) kilovolt distribution system located in the FTZ and HRFA, substituting steel poles in their place. Wood poles are constructed to withstand working loads under stress of fifty-six mile per hour (56 mph) wind speeds. These new steel poles are designed to withstand working loads under the stress of eighty-five mile per hour (85 mph) wind speeds. To date, SDG&E has installed over 5,000 new steel poles in the FTZ, and plans on further investment to continue to replace wood distribution and transmission poles with steel poles. These new steel pole facilities are being installed in conjunction with the application of higher strength conductors and increased spacing between lines beyond the requirements of Commission General Order 95, resulting in a decrease in the likelihood of live lines coming into contact with one another or arcing after being struck by flying debris. In addition, SDG&E's current design standards now reflect the use of steel poles over wood poles in the FTZ.

3. Undergrounding Line Segments and Facilities

SDG&E formed a technical team with expertise in the undergrounding of distribution systems and facilities. The team evaluated the undergrounding of various circuits, segments, elements, and equipment located in the HRFA. These experts provided senior management with an understanding of the potential for undergrounding portions of the overhead system in order to mitigate the risk of fire and the results are being used on circuit analysis to underground portions where feasible.

4. Special Case – Cleveland National Forest

The Cleveland National Forest Master Special Use Permit (MSUP) and Permit to Construct (PTC) for Power Line Replacement Projects. SDG&E currently operates and maintains a network of electric facilities located within the Cleveland National Forest (CNF). On September 19th, 2016, SDG&E received a Master Special Use Permit (MSUP) to operate and maintain facilities within CNF. The MSUP allows SDG&E to develop a series of projects and activities aimed at increasing safety and reliability of existing electric facilities within and near the CNF. Final approval for these projects and associated permits were received earlier in 2016 and work began in late September of 2016.

These projects will increase safety and reliability by replacing existing electric infrastructure that currently serves the USFS, emergency service facilities (fire, communication and other), campgrounds, homes, businesses, and other customers within the CNF and surrounding areas. The proposed projects include replacement of several existing 12 and 69 kilovolt electric facilities spread throughout an approximately 880 square mile area in eastern San Diego County. The existing electric lines located within CNF also extend outside of CNF boundaries. The overall project includes operational components complementing SDG&E's Community Fire Safety Program, which in turn includes community outreach, new fire prevention measures, and enhanced emergency response.

The project design was based on various recommendations addressing fire prevention and the Forest's environmental values and aesthetics. Using an analytical matrix reflecting elements of fire risks and environmental concerns, SDG&E and the Forest Service collaborated to determine which sections of the system should be upgraded.

Each segment required a custom solution based on many factors, including the location of the customer being served by the distribution system, the topography of the land, and various biological, cultural and environmental factors.

5. Automated Reclosers

As part of its Community Fire Safety Program, SDG&E has undertaken one of the largest deployments of state-of-the-art pulse reclosers, focusing heavily on the FTZ and HRFA. This equipment allows SDG&E to operate its system with significantly reduced energy flows during reclosing operations and be able to sectionalize various elements of its distribution system to better manage system operations and reliability. These pulse reclosers and other Supervisory Controlled and Data Acquisition (SCADA) controlled reclosers are managed remotely by SDG&E Distribution System Operators. In addition, SDG&E has implemented more sensitive relay settings to all SCADA reclosers in the HRFA. These sensitive relay settings provide very fast clearing of faults on distribution circuits and are remotely operated via SCADA, allowing for real-time adjustments triggered by adverse weather conditions.

6. Fire Detection and Mitigating the Threat of Fire

In addition to hardening the SDG&E electrical system, SDG&E is leveraging its assets to address fire threats. Along these lines, SDG&E has placed high-visibility, high-resolution rotating cameras on twenty-nine (29) key towers along those portions of the Sunrise Power Link transmission corridor located in the FTZ and HRFA. The cameras, which were activated in September 2012, can be controlled remotely, can rotate a full 360 degrees, and are coupled with an advanced centralized smoke-detection algorithm, which allows for earlier fire-detection and -warning capabilities.

SDG&E is also collaborating with the staff at the University of California, San Diego, responsible for the operation of the San Diego High-Performance Wireless Research and Education Network (HPWREN). This high-speed wireless data network is designed to connect hard-to-reach areas in remote environments and provide real-time data; the network includes earthquake sensors and mountaintop cameras, the latter having become a part of the emerging early fire-detection and fire-warning system being deployed in the San Diego backcountry. Currently, there are a total of 22 camera locations each with multiple camera views. In addition, SDG&E continues to work with multiple vendors specializing in early fire detection systems, and will continue to work with these vendors to develop new and improved ways of spotting fires before they become uncontrolled wildfires.

7. Testing and Deploying Emerging Technologies

SDG&E continues to evaluate and incorporate new technologies and equipment into its overhead electric system. SDG&E's Electric Distribution Engineering Department is responsible for evaluating and creating new equipment and use standards for emerging and pre-commercial technologies. Using equipment failure data, the department determines which technologies should be incorporated into the SDG&E system and which could be improved prior to application. This department continually evaluates the many new types of technologies which may improve electric reliability and public safety and gives special attention to technologies that may contribute to SDG&E's fire-safety goals and objectives. As an example, SDG&E is beginning to apply and analyze more advanced fault-clearing equipment that contain algorithms to improve the ability of the system to clear "wire-down" faults more quickly and which will serve to reduce the potential such faults might provide an ignition source.

8. Facility Inspection and Repair Program

In addition to adding, redesigning and replacing facilities and elements as described above, SDG&E has implemented more stringent monitoring and inspection programs in the FTZ and HRFA, which will intensify efforts to identify potential substandard system facilities and elements. As an example of these efforts, SDG&E is developing the use of pole-loading algorithms which more accurately calculate working loads and stresses. In addition, SDG&E coordinates these activities with communications infrastructure providers which jointly use SDG&E's poles and facilities.

SDG&E also maintains a comprehensive outage database which is used for reliability measurement and reporting purposes. Correlations between outages and locations are analyzed to determine whether certain equipment is prone to outages. This analysis is then matched to weather and other environmental conditions. Vegetation Management also maintains a comprehensive outage database. Outages related to trees and/or vegetation are investigated, documented, and results are analyzed to determine if additional pruning or removal measures are warranted to prevent any reoccurrence.

SDG&E is in the process of conducting facility testing using three-dimensional light detection and ranging ("LiDAR") surveys in the HRFA. This technology is being used to perform aerial scans of the sixty-nine kilovolt transmission system in the HRFA on a three-year cycle. These surveys provide detailed depictions of terrain, vegetation and other obstacles in the vicinity of SDG&E's facilities. This data is processed and modeled by the SDG&E Power Line System Computer-Aided Design and Drafting technology to depict actual field conditions. The information produced is used to ensure safe and proper clearances are met so as to reduce the potential for line faults occurring in the HRFA. Where potential issues are discovered, SDG&E will address them by September 1st, the calendar start of the peak fire season, subject to permitting requirements and other exigencies and conditions.

9. Oversight of Activities in the Rural Areas

Early in 2010, a multi-disciplinary technical team of subject matter experts within SDG&E, named the "Reliability Improvements in Rural Areas Team" (RIRAT), was formed and tasked with (a) developing a multi-dimensional understanding of the complex fire-risk issue within the SDG&E service territory, (b) assessing the conditions which pose the greatest risks related to fire, (c) determining the level of risk mitigation that could be provided by various proposed projects, and (d) assigning priorities to capital and operating programs and projects that could address fire-related risks in the FTZ. As is evident from the FTZ map shown in Figure 2 above, it is in these areas where the potential for uncontrolled wildfires, and potentially the greatest losses, is the highest. The RIRAT focused its attention on facilities and activities in these areas so as to assure cost-effective fire-prevention measures are promptly evaluated and implemented.

The RIRAT, among other things, oversaw the evaluation and implementation of the various fire-hardening activities described above.[3] Its work was guided by the following specific goals and objectives:

- Enhance the distribution system in the San Diego backcountry (a.k.a. FTZ and HRFA);
- Develop statistical measures for assessing distribution-system performance relevant to fire-related risks so as to provide an understanding of the scope of the risks that must be addressed and develop metrics for measuring improvement;
- Identify and prioritize areas posing the greatest fire-related risks;
- Develop guidelines and a portfolio of solutions to minimize fire-related risks;
- Develop a multi-year plan for the rebuilding of circuits of greatest fire-related risk;
- Review and analyze all reports of "wire-down" occurrences; and,
- Use the "wire-down" analysis to identify causes and best solutions so as to minimize future occurrences and further reduce fire-related risks.

In order to meet their goals, the RIRAT adopted the following guiding principles:

- Utilize risk-based prioritizations to maximize risk-mitigation;
- Improve design specifications to reduce the potential for igniting fires;

[3] The Rural Area Team also oversaw the design and implementation of operations, maintenance and inspection programs and activities in the San Diego backcountry. Those activities and programs are discussed in further detail later in this section.

- Consider and, to the extent prudent and cost-effective, employ technology-based solutions to reduce fire risks and improve overall system reliability;
- Prioritize system-rebuild efforts based on a matrix of available projects, considering the most important input factors such as the recent occurrence of a “wire-down”, wind and weather conditions, fire risks, values at risk, outage history, conductor type, condition of equipment, environmental conditions, and resulting customer impacts;
- Systematically consider and evaluate the following options:
    - Fire-hardening sections of feeder circuits or individual circuit branches;
    - Undergrounding by traditional undergrounding or cable-in-conduit;
    - Adjusting protective equipment by revising settings, balancing loads, adding reclosers, replacing expulsion fuses with fault tamers, and/or reducing fuse size; and,
    - Employing new methods and/or technologies, such as spacer cables, wireless fault indicators, “off-grid” solutions, and Smart Grid technologies;
- Replace higher-risk equipment based upon statistical analytics; and,
- Use tree guards and/or insulated aerial cables.

Previously, the RIRAT oversaw the evaluation and approval processes for the various system improvements and capital projects described above, and specifically addressed system design and facilities from the perspective of minimizing fire-related risks in the rural areas included in the FTZ and HRFA. In 2013, the RIRAT and associated processes were incorporated into a new program called the Fire Risk Mitigation (FiRM) program. This new effort is discussed in greater detail below.

10. Fire Risk Mitigation (FiRM) Program

In 2013, SDG&E started an overhead distribution fire hardening re-building effort with a program called the Fire Risk Mitigation (FiRM) Program. FiRM addresses fire risk by hardening facilities in the HRFA and by replacing aged line elements, utilizing advanced technology, and safeguarding facilities from known local weather conditions.

The program is compiled of dozens of projects annually which focus on re-building in areas of the highest fire risk. Statistics from the RIRAT are coupled with information about “known local conditions” to scope projects.

II. Operational Practices for Reducing the Risk of Ignition

Despite all the efforts SDG&E might take in designing, redesigning, improving, replacing, and fire-hardening various elements of its overhead electric system, there could be unanticipated events posing potential risks. To address these unanticipated events, SDG&E has designed and implemented a number of operations, maintenance and inspection programs directly addressing fire prevention and the mitigation of effects from fires.

A. System Management: Quality Assurance and Quality Control

SDG&E has enhanced its system-management programs so as to mitigate that, to the extent possible, SDG&E’s overhead system, facilities and equipment become the source of ignition for a fire. These programs generally encompass inspection and maintenance functions, and have been modified to focus on minimizing the probability that damaged or aging facilities will provide the ignition source for a fire. Inspection and repair of the SDG&E transmission and distribution systems have particularly intensified in the FTZ and HRFA. To that end, SDG&E performs a General Order 165-type system maintenance patrol of the entire overhead electric system in the FTZ on an annual basis. Safety related non-conformances identified in those patrols are scheduled for follow up repair. These patrols are twice as frequent as that required of the overhead system in general. In addition, SDG&E has implemented Quality Assurance and Quality Control standards and programs throughout its service territory, with a special focus in the HRFA during fire season.[4] These proactive programs are designed to identify potential structural and mechanical problems on the system. Distribution facilities within the HRFA are currently inspected in detail on a three-year cycle and corrections are made in the same year before fire season begins. Where the facility in need of repair is owned by a party other than SDG&E, *e.g*., by a communication infrastructure provider, SDG&E will issue a notice to repair to the facility owner and work with the facility owner to ensure necessary repairs are completed promptly. SDG&E's operational goal, subject to permitting requirements and other exigencies and conditions, is to complete all facility and equipment repairs before September 1st of each year. However, for 2016, because in large part due to the declared drought emergency by the Governor of California, SDG&E completed repairs one month early[5].

Annual adjustments to the HRFA map, if any, are also reflected in the scope of the Quality Assurance and Quality Control program.

The SDG&E Transmission Quality Assurance and Quality Control program is similar in nature to its distribution counterpart. Transmission lines within the HRFA, subject to any annual adjustments to the HRFA boundaries that might be made based on updated data, are inspected on a three-year cycle.[6] Matters of concern are identified for repair, and SDG&E makes best efforts, subject to permitting requirements and other exigencies and conditions, to complete all repairs within the HRFA by September 1st.

B. Enhanced Vegetation Management and Clearance Goals

SDG&E currently maintains records for over 463,000 trees located near its power lines. Almost 100,000 of these trees are located within the SDG&E HRFA. All of the 450,000 inventory trees in SDG&E's database are monitored using known species and specimen growth rates, with additional consideration given to the amount of rainfall occurring during periods affecting overall tree growth, and past pruning practices. Each tree is visited by a staff arborist on an annual cycle. The annual inspections include routine maintenance and hazard tree assessments to ensure that every tree remains fully compliant for the duration of the cycle and/or is trimmed according to accepted standards and clearances. Prior to fire season, SDG&E requires vegetation management contractors to perform annual training on hazard tree assessment. This refresher training helps set the stage for a second inspection and corresponding tree-hazard evaluation is performed for each tree in the HRFA. The tree evaluation includes 360-degree assessment of every tree within the 'strike zone' of the conductors and maximize time-of-trim clearances. To the extent unsafe clearances may exist, an order to clear vegetation is issued and trimming is completed prior to September 1st of each year. In addition, SDG&E conducts off cycle patrols for Century Plant blooms and bamboo. The off- cycles are performed throughout the entire service territory during their peak growth to prevent the new growth from encroaching the minimum clearances of overhead conductors. These activities ensure safe minimum vegetation clearances are achieved prior to the peak fire season.

In addition, SDG&E continues a system-wide robust tree program to replace problematic species. The SDG&E Right Tree-Right Place Program assists customers in the selection of the tree species and planting locations which will minimize interference with nearby power lines and facilities. SDG&E also offers free tree replacements in the event that an existing tree cannot be maintained safely near power lines and should be removed rather than trimmed. Notably, SDG&E has, for the 13th consecutive year, been recognized by the National Arbor Day Foundation as a "Tree Line USA" utility company in recognition of our "best practices" combining worker education and training, public outreach, quality tree care, and system reliability.

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[4] The Quality Assurance and Quality Control program augments the five-year inspection cycle imposed under the provisions of Commission General Order 165.

[5] September 1st marks the beginning of the "fire season," although the highest risks of and from fire in the SDG&E service territory typically peak in October and November.

[6] The three-year inspection cycle for transmission facilities coincides with the normal cycle specified in SDG&E's Transmission Maintenance Practice manual.

SDG&E also manages over 35,000 poles within the CAL FIRE jurisdictional areas that have been designated as "subject poles." For poles within the CAL FIRE jurisdiction that bear these "non-exempt" attachments, SDG&E is required to perform "pole brushing," that is, clearing all vegetation within a ten-foot radius of the pole. To further reduce potential ignition sources, vegetation management works closely with the FiRM Team and engineering to reduce the number of non-exempt power line components by replacing such equipment, where feasible, with exempt equipment.

Lastly, SDG&E Vegetation Management provides electrical equipment training with Cal Fire representatives. This training is in preparation for a Cal Fire Inspection for PRC 4292 and 4293 in the State Responsible Areas. Over the years, the program has developed a great working relationship with Cal Fire. The training provided helps to ensure SDG&E is maintaining proper clearances of vegetation to conductors and equipment as we enter the fire season. Cal Fire Inspections have been jointly performed with SDG&E, however, the training is intended for Cal Fire to better understand how our system operates and what equipment requires mitigations to prevent an ignition source. This training can be used by Cal Fire while they are conducting their own day to day operations and inspections in the field.

C. Coordination with Communications Infrastructure Providers

In 2012, SDG&E developed and began using a new web-based communication conduit to simplify the recordkeeping for, and approval, inspection and repair of, pole attachments owned by Communications Infrastructure Providers. Named the "Telecommunication Equipment Attachment Management System" (TEAMS), the system was placed in operation in October 2012. TEAMS provides a direct communication link between SDG&E and Communications Infrastructure Providers and a shared-recordkeeping functionality. There are four key benefits provided by TEAMS. First, TEAMS enables Communications Infrastructure Providers to file pole attachment applications on-line – tracking of these applications and accompanying documents can now be performed electronically. This provides the baseline data necessary for SDG&E to monitor the equipment and resulting working loads placed on SDG&E facilities. Second, all attachment applications can be delivered and tracked by the applicant and SDG&E. Third, this system is also used for requesting and tracking requests for pole transfers and other transactions involving changes to equipment on jointly used poles with communications-related attachments. Finally, if during an inspection SDG&E discovers any pole attachment to be non-compliant and/or in need of repair, notices and the tracking of repairs will be done through TEAMS. This provides both SDG&E and the Communications Infrastructure Providers with electronic records of the actions taken by both to assure overhead facilities are in good repair and less of a risk to be a source of ignition for a fire.

D. Workforce Training and Field Practices

SDG&E believes that an important line of defense against the ignition of fires is a well-trained and alert workforce. Internally, SDG&E has created a culture of fire prevention. To that end, SDG&E has adopted an extensive set of work rules and complementary training programs designed to minimize the likelihood that SDG&E's facilities or field work not be the source of ignition for a fire. The rules and training programs are in large part embodied in SDG&E Electric Standard Practice No. 113.1 (ESP 113.1), which specifically addresses wildland fire prevention and fire safety. ESP 113.1 was developed by SDG&E's expert team of Fire Coordinators based on their experience (over 100 years of combined work experience) in fire behavior, fire prevention and firefighting techniques. ESP 113.1 also incorporates principles and concepts drawn from various federal, state and local protocols and standards addressing wildland fire prevention and suppression.

ESP 113.1 describes the conditions under which the threat of fire is considered high and the changes in field practices and resources which will be implemented as the threat increases. These changes affect work rules, equipment which will be made available to work crews under different conditions, and even worker attire. ESP 113.1 specifies minimum training requirements and annual refresher requirements for all SDG&E and contract personnel working in the FTZ and HRFA. The work rules and training also apply to personnel working in SDG&E's Electric Distribution Operations and Electric Grid Operations control centers.

As an essential part of ESP 113.1, SDG&E has reviewed and has an understanding of the Incident Command System. This system provides a structure for disciplined communications and decision-making under the threat of fire as well as during fire emergencies. SDG&E field supervisors are assigned varying levels of on-scene command responsibilities in terms of coordinating and managing the SDG&E response to threat and emergency conditions. Training in the Incident Command System protocols and responsibilities is a key element of the annual training conducted by SDG&E. ESP 113.1 is also reviewed annually and any needed changes adopted and made known to all affected.

III. Mitigating the Threat of Fire: Awareness and Readiness

A. Situational Awareness

Although the risk of fire is a year-round reality, there are certain recurring environmental and weather conditions, particularly during the late summer and early fall, when the risks of and from fire, particularly from uncontrolled wildfires, in the SDG&E service territory are abnormally high and the dangers most severe. SDG&E's fire-prevention and risk-mitigation activities begin with intensive data gathering and data analysis so that, if and when these abnormal and dangerous conditions are anticipated or occur, SDG&E is prepared to mobilize personnel and resources to abate, mitigate and respond to these conditions and any potential fire threats.

SDG&E has developed extensive, high-resolution weather databases which are used to identify those areas where the threat of and from uncontrolled wildfire is the highest and/or most dangerous. The areas which SDG&E monitors most closely are shown in the FTZ and HRFA maps – these areas are distinguished by the coincidence of high winds and combustible vegetation. SDG&E's weather databases are constantly updated using weather data provided by a number of sources, including the United States National Weather Service, local airports, and SDG&E's proprietary mesonet located throughout SDG&E's service territory.[7] SDG&E's mesonet provides over 200,000 data points per day.[8]

SDG&E has three (3) full-time degreed and experienced meteorologists on staff. Their responsibilities include analyzing the historical databases and, importantly, monitoring incoming data in real-time. They also provide a detailed daily forecast of weather conditions relevant to SDG&E's operations. Their forecasts, a combination of heat, humidity, wind, and other conditions, are combined into an "Operating Condition" assessment, which tracks the potential for fires occurring in any region of the SDG&E service territory. There are four (4) Operating Conditions used for these purposes:

- **Normal Condition**: This condition is declared when it has been determined by the SDG&E meteorologists and Fire Coordinator team that the burn environment is not conducive for wildfires within the SDG&E service territory;

- **Elevated Condition**: This condition is declared when it has been determined by the SDG&E meteorologists and Fire Coordinator team that the burn environment has become conducive for wildfires within the SDG&E service territory;

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[7] The location of SDG&E's weather stations is shown on the Fire Threat Zone and Highest Risk Fire Area map attached as an appendix to this Fire Prevention Plan.
[8] SDG&E makes its weather data available to public agencies and the general public free of charge through several popular media outlets, including the Internet.

- **Extreme Condition**: This condition is declared when it has been determined by the SDG&E meteorologists and Fire Coordinator team that a combination of high winds, low relative humidity, and the burn environment will create critical fire weather conditions; and,

- **Red Flag Warning (RFW) Condition**: Red Flag Warning Condition is declared by the National Weather Service when high *winds and low relative humidity are forecasted to occur for an extended period of time.* Depending on the condition reported and broadcast by the meteorological staff, various operational changes and rules appropriate to each condition will be triggered and implemented.

A table summarizing the four conditions and the associated operational responses to each is shown below:

CONDITION	Normal Condition **Fire Potential Index 1-11** Fuel and weather conditions are no longer conducive to significant fire growth. Based on fire indices and Fire Coordinator / Meteorologist Recommendation		Elevated Condition **Fire Potential Index 12-14** The burn environment of a specific area or district has become conducive for a large wildfire within the SDG&E service territory.		Extreme Condition **Fire Potential Index 15 and above** An extreme operating condition will be declared when the burn environment of a specific area or district has become conducive for a catastrophic wildfire within the SDG&E service territory. .		Red Flag Condition (NWS) RFW: Relative Humidity ≤ 15%, with sustained winds ≥ 25 mph and/or frequent gusts ≥ 35 mph (duration ≥ 6 hours) Declared by NWS	
	Distribution	Transmission	Distribution	Transmission	Distribution	Transmission	Distribution	Transmission
Highest Risk Fire Area	No change to reclosing policy. Line will be tested by recloser action.	No change to reclosing policy. Line will be tested by recloser action.	All reclosers will be turned off.		All reclosers will be turned off. Enable Sensitive Relay Setting at direction of EDO.		All reclosers will be turned off. Enable Sensitive Relay Setting at direction of EDO.	
			TESTING		TESTING		TESTING	
			Distribution	Transmission	Distribution	Transmission	Distribution	Transmission
			SGF Targets: Patrol entire line or line segment before energizing. Non-SGF Targets: Patrol line segment to load-side sectionalizing device before energizing.	Patrol entire line or line segment before energizing.	SGF Targets: Patrol entire line or line segment before energizing. Non-SGF Targets: Patrol line segment to load-side sectionalizing device before energizing.	Patrol entire line or line segment before energizing.	SGF Targets: Patrol entire line or line segment before energizing. Non-SGF Targets: Patrol line segment to load-side sectionalizing device before energizing.	Patrol entire line or line segment before energizing.
			If a Distribution outage is caused by a Transmission/Substation outage, Distribution may re-energize without a patrol, as directed by Control Center Management, SDG&E FC and/or Meteorologist.		If a Distribution outage is caused by a Transmission/Substation outage, Distribution will consult with Fire Coordinator / Meteorologist and evaluate re-energization without a patrol. Crew Deployment Plan Activated by District		Crew Deployment Plan Activated Staging Sites Include: All C&O Centers Viejas, Santa Ysabel, Jamul, Del Mar, Fallbrook At a > 56 mph wind gust forecast, EDO will stage field observers, close to affected areas.	
FIRE THREAT ZONE	No change to reclosing policy. Line will be tested by recloser action.		All reclosers will be turned off.		All reclosers will be turned off.		All reclosers will be turned off.	
			TESTING		TESTING		TESTING	
			Distribution	Transmission	Distribution	Transmission	Distribution	Transmission
			SGF Targets: Patrol entire line or line segment before energizing. Non-SGF Targets: Patrol line segment to load-side sectionalizing device before energizing.	Patrol entire line or line segment before energizing.	SGF Targets: Patrol entire line or line segment before energizing. Non-SGF Targets: Patrol line segment to load-side sectionalizing device before energizing.	Patrol entire line or line segment before energizing.	SGF Targets: Patrol entire line or line segment before energizing. Non-SGF Targets: Patrol line segment to load-side sectionalizing device before energizing.	Patrol entire line or line segment before energizing.

Figure 3. Operating chart for Normal through Red Flag Conditions.

The daily weather forecast and Operating Condition are broadcast by electronic media to personnel whose activities are affected by the declaration of the Operating Condition – the forecast, particularly when the threat of fire is high or rising, will be updated and rebroadcast as conditions warrant and as the staff meteorologists determine is appropriate. The forecast is broadcast in real-time to a large audience of SDG&E employees. Personnel receiving these weather forecasts are trained to adjust their activities, duties and priorities based upon the Operating Condition reported by the staff meteorologists.

Generally, as actual or forecasted wind speeds, measured in terms of both sustained winds (the average wind speed across ten-minute intervals) and wind gusts (the highest wind speed occurring during a three-second period within a ten-minute interval), increase, the Operating Condition will change (or "be elevated"), from "Normal" to "Elevated Condition" or "Extreme Condition" or "Red Flag Condition," depending on environmental and weather conditions and the strength of the winds being experienced or forecasted. With each step-change in the Operating Condition, personnel are placed on appropriate levels of alert. In addition, the level of system monitoring and, ultimately, system operations and activities, are elevated according to the prevailing Operating Condition. Most importantly, as wind speeds increase, SDG&E deploys an increasing number of field crews, troubleshooters and Wildland Fire Prevention resources to areas with the highest winds and where the greatest threat of fire exists, so as to increase the probability that fires will be detected early and a response will occur as soon as possible.

B. The Fire Potential Index

SDG&E has developed a comprehensive assessment tool, known as the "Fire Potential Index" (FPI) that is used as a tool for making operational decisions which will reduce fire threats and risks. This tool converts environmental, statistical and scientific data into an easily understood forecast of the short-term fire threat which could exist for different geographical areas in the SDG&E service territory. The FPI is issued for a seven-day period and provides SDG&E personnel time, during which they may plan and prepare accordingly.

The FPI reflects key variables such as the state of native grasses across the service territory ("green-up"), fuels (ratio of dead fuel moisture component to live fuel moisture component), and weather (sustained wind speed and dew point depression). Each of these variables is assigned a numeric value and those individual numeric values are summed to generate a Fire Potential value from zero (0) to seventeen (17), each of which expresses the degree of fire threat expected for each of the seven days included in the forecast. The numeric values are classified as "Normal", "Elevated", and "Extreme".

The state of native grasses, or "Green-Up Component", of the FPI is determined using satellite data for various locations. This component is rated on a 0-to-5 scale ranging from very wet (or "lush") to very dry (or "cured"). The scale is tied to the NDVI, which ranges from 0 to 1,[9] as follows:

Table 3. FPI Green-Up Component

Very Wet/Lush: 0.65 to 1.00	0.60 to 0.64	0.55 to 0.59	0.50 to 0.54	0.40 to 0.49	Very Dry/Cured 0 to 0.39
0	1	2	3	4	5

The Fuels Component of the FPI measures the overall state of potential fuels which could support a wildfire. Values are assigned based on the overall state of available fuels (dead or live) for a fire using the following equation:

$$FC = FD / LFM$$

Where FC represents "Fuels Component" in the scale below, FD represents Fuel Dryness Level (using a 1-to-3 scale)[10] and LFM represents Live Fuel Moisture (percentage).

[9] The Normalized Difference Vegetation Index ("NDVI") is a simple graphical indicator that can be used to analyze remote sensing measurements, typically but not necessarily from a space platform, to assess whether the target area under observation contains live green vegetation or not. More information on the NDVI scale is available at the following address: http://en.wikipedia.org/wiki/Normalized_Difference_Vegetation_Index.

[10] These values are taken from the Southern California Geographic Area Coordination Center, an interagency support center for fire protection and suppression. More information regarding this agency can be found at the following address: http://gacc.nifc.gov/oscc/ .

The product of this equation represents the fuels component that is reflected in the FPI as follows:

Table 4. FPI Fuels Component

Very Wet					Very Dry
1	2	3	4	5	6

The weather component of the FPI represents a combination of sustained wind speeds and dew-point depression as determined using the following scale:

Table 5. FPI Weather Component

Dewpoint/Wind	≤4 knots	5 to 9	10 to 14	15 to 19	20 to 24	>24 knots
>50ºF	2	3	3	4	5	6
40ºF to 49ºF	2	2	3	3	4	5
30ºF to 39ºF	1	2	2	3	3	4
20ºF to 29ºF	1	1	2	2	3	3
10ºF to 19ºF	0	0	1	1	1	1
<10ºF	0	0	0	0	0	0

The individual numeric values representing the three variables reflected in the FPI, shown above, are combined and placed on the following scale:

Table 6. Fire Potential Index (FPI)

Normal	Elevated	Extreme
< 12	12 – 14	> 15

The FPI was developed by a team made up of SDG&E meteorologists, fire coordinators, and statistical analysts. The team has validated the FPI values and their usefulness by recreating historical values for the past ten (10) years. The historical results bore a very strong correlation to actual fire events in terms of the severity of past fires and, in particular, provided very accurate information as to when the risks of uncontrolled and large-scale wintertime fires were high. SDG&E expects to tie proactive and reactive operational practices and measures to the FPI values, with the further expectation that SDG&E will be able to reduce the likelihood its facilities and operations will be the source of ignition for a fire during times when the risk of fire as measured by the FPI elevated or extreme.

C. The SDG&E Emergency Operations Center (SDG&E EOC)

In the event the National Weather Service declares a Red Flag Warning (RFW), the SDG&E meteorologists will elevate the warning broadcast to SDG&E personnel to the highest level of alert. RFWs are typically issued when relative humidity is at or below fifteen percent (15%) and sustained winds are expected to reach twenty-five miles per hour (25 mph) or higher and/or frequent wind gusts exceeding thirty-five miles per hour (35 mph) are expected for a duration of six or more hours. A RFW will also be issued under "dry lightning conditions," where a lightning event is expected in the absence of enough precipitation to wet potential fuels which are considered critically dry. Upon the declaration of a RFW, SDG&E may activate the SDG&E EOC depending on critical fire weather conditions and forecasted wind speeds.

Because RFW conditions present threats to the SDG&E electrical system and its component facilities and equipment, specific members of SDG&E management and operating departments are placed on alert when these conditions are present and the National Weather Service has issued a RFW. Upon such a declaration, these senior managers and operating personnel are called upon to appropriately staff the SDG&E EOC, a secure and dedicated facility which serves as a command center for SDG&E operations under high-threat conditions. The activation of the SDG&E EOC assures that appropriate decision makers and experts are assembled together, providing for the close monitoring of the electrical system and operations by all involved departments and disciplines. As the situation changes, the SDG&E EOC personnel will take appropriate and timely actions as necessary in order to protect public safety and defend against the threat that SDG&E's electrical facilities may become a source of ignition.

D. Crew Mobilization and Deployment Strategy

During an Extreme Operating Condition or Red Flag Condition, the management of the SDG&E Electric Distribution Operations and Electric Grid Operations control centers work to coordinate the assignment of appropriate and needed resources to each of the affected regional operating districts. At minimum, Electric Troubleshooters and personnel from the Wildland Fire Prevention resources are made available for immediate response to address fire threats or events. If the event is more severe, additional resources will be coordinated between and assigned from Electric Distribution Operations, Electric Grid Operations, Electric Regional Operations, Construction Services, and Kearny Substation and Transmission Operations Center to manage the event. Field personnel may be assigned to observe an area forecasted to experience the most adverse weather conditions – these personnel are under instructions to report flying debris, vegetation damage, or significant conductor movement. Based on these field observations, SDG&E deploys appropriate resources to address the fire threats posed by these conditions.

E. Field Patrols

Under Elevated, Extreme, and Red Flag Warning Conditions, SDG&E may perform an appropriate patrol of any circuit sustaining a forced outage. Qualified electrical workers are dispatched to inspect the circuit, determine the cause of the outage, and evaluate the physical integrity of the circuit. Upon the appropriate evaluation, restoration will commence when repairs are completed and/or there is no longer a threat to public safety or the electric system. In some cases, and weather permitting, field personnel may be positioned to observe and test the affected circuit.

Training and refresher drills for field patrols are conducted and are designed to exercise the assembly of Patrol Teams and the communication hierarchy of the SDG&E Incident Command System. These drills ensure effective management of the Restoration Patrols and disciplined communications between Patrol Teams, Patrol Leaders, Fire Coordinators, Meteorology and Incident Commanders.

F. Santa Ana Wildfire Threat Index (SAWTI)

San Diego Gas & Electric (SDG&E), The U. S. Department of Agriculture/U.S. Forest Service, and UCLA, in collaboration with CALFire, the Desert Research Institute and the National Weather Service unveiled a new web-based tool in September 2014 to classify the fire threat potential associated with the Santa Ana winds that are directly linked to the largest and most destructive wildfires in Southern California. The Santa Ana Wildfire Threat Index (SAWTI) categorizes Santa Ana winds based on anticipated fire potential. The index uses wind speed, humidity, and fuel conditions to determine how severe an event will be in terms of its impact upon the fire environment. The SAWTI, which includes four classification levels from “Marginal” to “Extreme,” will be used to help fire agencies, other first-responders and the public determine the appropriate actions to take based on the likelihood of a catastrophic wildfire fueled by high winds. The Santa Ana Wildfire Threat Index uses a comprehensive, state-of-the-art predictive model that includes dead fuel moisture, live fuel moisture, and the greenness of annual grasses to create a detailed daily assessment of the fuel conditions across Southern California. This information is coupled with calibrated weather model output (comprised of wind speed and atmospheric moisture), to generate a 6-day forecast of Large Fire Potential. The Large Fire Potential is then compared to climatological data and historical fire occurrence to establish the index rating.

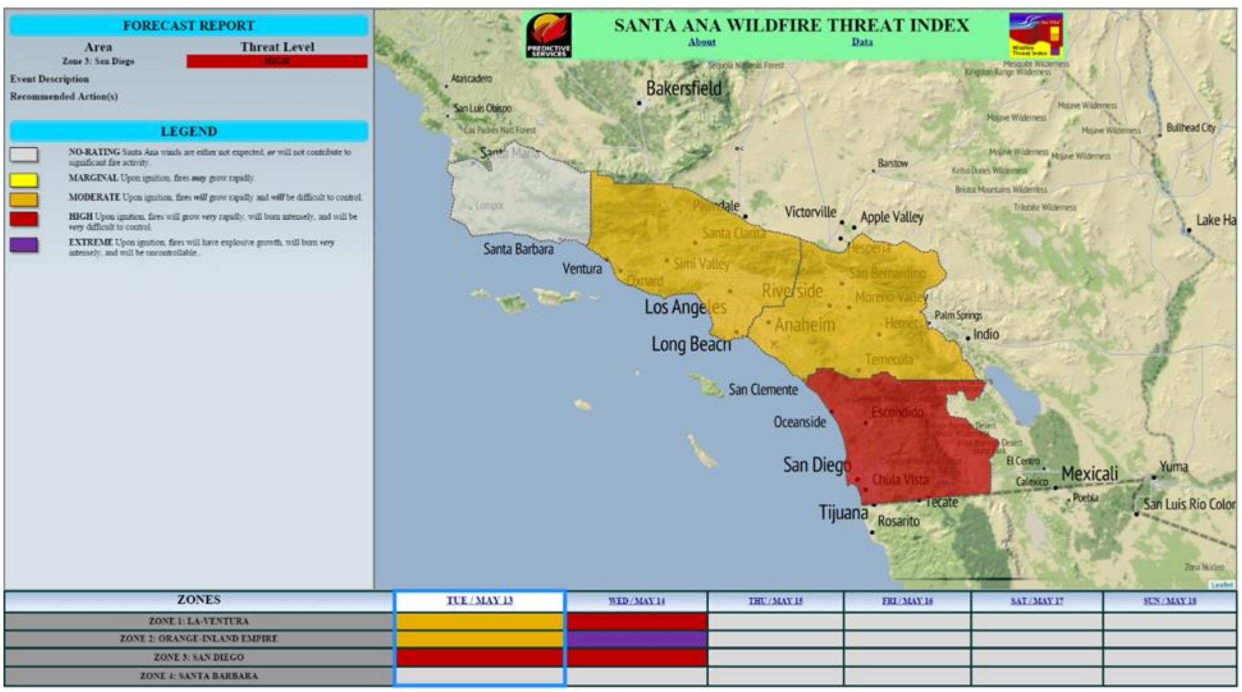


Figure 4. Santa Ana Wildfire Threat Index website example.

A number of fire agencies and forecasting models have used pieces of this data and various interpretations of what the information means relative to the development and potential impact of a Santa Ana wind event. This tool, however, for the first time incorporates all of the data into a single site that is available not only to first responders and government agencies, but also to the public. One of the most significant elements of the index is the “call to action” associated with each level of the index, which includes recommended steps based on the potential severity of the forecasted Santa Ana.

IV. Fire Suppression and Recovery

When fire risk is high and a wildland fire occurs, SDG&E may mobilize its available resources (Wildland Fire resources and/or Industrial Fire Brigade, see below) as the situation dictates, to assist in the suppression of the fire and in recovery activities. These resources could be made available, if requested, to the public agencies with responsibility for fire suppression and recovery.

A. Fire Coordination Personnel

SDG&E employs a full-time staff of Fire Coordinators and contracts for additional resources and personnel on an as-needed, project-by-project basis. The six Fire Coordinators currently on staff have over a century of firefighting experience and are experts in fire behavior, fire prevention and firefighting techniques. The Fire Coordinators serve as the direct link between SDG&E and emergency-response agencies. They also serve as the single point of contact for the fire agency Incident Command System; provide periodic updates to fire emergency personnel and SDG&E personnel; establish radio and communications assignments for every fire event; assist in the coordination of activities related to de-energizing and re-energizing power lines; and update on-scene personnel, control centers, service dispatch, and the SDG&E regional operations centers as to the status of each incident. The Fire Coordinators are active in professional forums, seminars and training throughout the service territory to ensure state-of-the-art fire practices are incorporated into SDG&E operations and practices. The Fire Coordinators also participate in engineering and operational meetings to advise SDG&E personnel regarding fire threats and prevention.

The Fire Coordinators also share information with the firefighting agencies within the SDG&E service territory and, on a rotating basis, provide those agencies with electrical and gas safety training.

B. Firefighting Assets and Resources

1. Wildland Fire Prevention Resource

SDG&E has contracted for wildland fire-suppression trucks and trained firefighting personnel. Up to eight (8) fire suppression trucks are provided to SDG&E throughout the fire season and are available to SDG&E on an on-call basis for the other months of the year. These resources are dispatched with work crews during days on which the threat of fire is high. Prior to the commencement of the day's work, firefighting personnel provide instruction and advice specifically addressing fire risks and the potential mitigation and prevention measures the crews should observe in order to eliminate or reduce the likelihood of an ignition. The firefighting crews also pre-deploy hose lines and tools as a precautionary measure and monitor the work performed by the SDG&E crews.

In the event of an ignition, the firefighting personnel have the equipment, skills and ability to respond and extinguish fires quickly.

When the fire risk is very high, SDG&E deploys additional fire trucks as needed pursuant to a proactive staging plan triggered by the declaration of Extreme Conditions and Red Flag Warning Conditions. These resources are strategically placed throughout the service territory to be available as needed.

2. Aviation Services Department

The Aviation Services department is responsible for contracting aviation assets and personnel, planning, supporting and managing day-to-day aviation activities, measuring aerial job performance, and supporting fire-suppression activities. With respect to its fire-suppression responsibilities, the department coordinates the provision of SDG&E aerial resources to firefighting efforts. The department also oversees SDG&E's contributions to, and participation in, the local Aerial Firefighting Protection Fund in collaboration with the San Diego Fire Department and the San Diego County Office of Emergency Services.

SDG&E has also contracted with Erickson Air-Crane for the provision of a Type 1 firefighting helicopter from August 1st through November 30th through the year 2016, or as critical fire weathers dictate. This contract is under the supervision of the Department.

3. The Industrial Fire Brigade (IFB)

SDG&E has contracted a full-time 24/7/365 Industrial Fire Brigade. The IFB is specially trained in fighting fires involving electrical equipment and flammable liquids. The IFB members are housed in facilities located near the geographical center of the SDG&E service territory and are fully equipped to handle utility-related fire emergencies.

The IFB has available four (4) portable fire-suppression trailers, each provisioned with 300 gallons of Class B Alcohol Resistant firefighting foam, 500 pounds of PKP Dry Chemical extinguishing agent, a 500 gallon per minute monitor, and two self-educating handlines designed to work with hydrants or other mobile fire apparatus. These trailers are located in strategic locations to SDG&E's assets and service territory. These fire-suppression trailers are available upon request to external fire agencies.

The IFB is also responsible for the development of comprehensive pre-emergency response plans for each SDG&E facility. These plans will be developed for SDG&E's high-value assets first, including SDG&E's power plants, peaker stations, and extra-high-voltage substations. These plans are designed to improve emergency response at each of these facilities significantly.

4. Miscellaneous Assets

SDG&E maintains a collection of portable emergency generators which may be deployed on an as-available basis to customer locations to provide temporary power during electrical outages. If available, these generators could be made available to providers of essential services as a first priority or to other customers upon request and on a case-by-case basis.

SDG&E has been proactive in developing programs and partnerships which significantly improve emergency-event communications both internally and in cooperation with emergency-services agencies. In this regard, SDG&E has acquired Mobile Field Command Trailers and satellite phone booths for deployment to supplement essential communications during emergencies. As part of efforts to improve internal communications in remote areas, SDG&E has partnered to create the Area Situational Awareness for Public Safety Network (or "ASAPnet"). ASAPnet is designed and deployed to provide internet connectivity to and between more than seventy (70) fire stations throughout the San Diego County backcountry.

C. Recovery Activities

At the end of emergency events, the SDG&E Emergency Operations Center conducts a debrief and prepares an after-action report that identifies action items to correct or improve future responses.

Also, SDG&E employees participate in a number of volunteer and charitable activities on an ongoing basis – this participation expands dramatically following local disasters. These activities include providing human, financial and other resources to the American Red Cross, San Diego County Recovery, the San Diego Burn Institute, and many other worthy organizations.

D. Fire Incident Data Collection Plan

Contained within on-going Fire Safety Order Institute Rulemaking proceedings, a plan was developed for California investor-owned utilities (IOU's) to collect and report data to the California Public Utility Commission's (CPUC) Safety and Enforcement Division (SED) regarding power line fires, and for SED to use this data to (1) identify and assess systemic fire safety risks associated with overhead power line facilities and (2) formulate measures to reduce the number of fires ignited by power lines. SDG&E has adopted the plan developed by the parties within the proceeding and further has created a plan specific to SDG&E's initiation and implementation of these requirements to insure compliance.

The CPUC/SED requirements can be summarized by the following bullets:

- Any data collection and subsequent data reporting will be in addition to the incident reporting requirements currently required of the utilities.
- Data needs to be consistent using the default formats provided within the proceeding.
- New fire reporting requirements should not be limited to designated "fire threat" zones or districts but for all areas.
- Fire reporting shall meet the following criteria;
    - Self-propagating fire of material other than electrical and/or communication facilities.
    - The resulting fire traveled greater than (1) meter from the ignition point.
    - The utility has knowledge the fire occurred.
- Information shall be objective and factual.
- Utilities will report data in an annual report for the previous calendar year before April 1st of each year.
- The data collected is raw data that is correct to the best of the utility's knowledge at the time of submission.

The SDG&E Data Collection plan further specifies responsibilities and accountability for compliance with this plan;

- <u>Fire Coordination:</u> The Fire Coordination group will continue to manage the current fire database and continue to work with Emergency Services to move this process into the SDG&E Emergency Incident Reporting (EIR) system. The transition will occur without disruption or loss of data as well as be able to generate the required report. All qualifying fires will be reported to the On-duty Fire Coordinator.
- <u>Compliance Management:</u> As part of their annual calendar, Compliance Management will track and insure that this reporting requirement to the SED is met in the required timeframe.
- <u>Claims, Legal, & Regulatory:</u> Will continue their role and responsibilities for fires related to SDG&E facilities as well as review the annual report prior to submission.
- <u>Control Centers:</u> Both Distribution Operations and Grid Operations supervisors and operators will understand what denotes a reportable fire and assist in ensuring qualifying fires are reported to the On-duty Fire Coordinator.
- <u>Electric Regional Operations and Transmission Construction Maintenance:</u> Troubleshooters, Construction Supervisors, and line personnel will understand what denotes a reportable fire and assist in ensuring qualifying fires are reported to the On-duty Fire Coordinator.
- <u>Training:</u> An initial training and annual refresher training will be developed by the Fire Coordination group and delivered to the Control Center and District field personnel to insure compliance with these requirements.
- <u>Root Cause Analysis:</u> The data collected will continue to be shared internally with the T&D engineering group for further root cause analysis to help determine fire mitigation measures that make sense to implement in the future.

V. Community Outreach and Public Awareness

SDG&E has created a multi-level approach to community education and outreach as our contribution to public awareness of fire threats, fire prevention and emergency preparedness. The key elements of this approach are described below.

A. Fire Safety Stakeholder Collaboration and Communication

In 2009, SDG&E customers and community leaders were invited to participate in a fire safety collaboration process. About 40 stakeholders – representing local schools, water districts, disability rights advocates, consumer groups and fire departments – worked with SDG&E for more than a year to develop a joint fire-prevention plan. This process was facilitated by a federal mediator. The process produced more than 100 potential solutions aimed at preventing the occurrence of major fires. SDG&E has implemented many of these solutions as identified by the stakeholders, including deactivating automatic reclosers, hardening its overhead electric system, replacing wood poles with stronger steel poles and larger conductors, and undergrounding portions of the electrical system, where feasible.

SDG&E frequently invites community leaders, government agencies and the public at-large to participate in a collaborative fire-safety process to continue dialogue and partnerships regarding public safety.

B. Partnering with Firefighting Agencies

SDG&E partners with the San Diego County Fire Chiefs' Association and other organizations to address a range of fire prevention and emergency activities. These partners include; fire agencies, Fire-Safe councils, Community Emergency Response Teams (CERTs) and other community organizations. Among the activities addressed through these partnerships are, including but not limited to:

- Participation in coordinated multi-agency preparedness and emergency events;
- Support and participate in the annual County Wildland Drill; coordinated by the San Diego Fire Training Officers;
- Participation in Fire Station and Fire Safe Council Open Houses;
- Emergency preparedness radio spots with the San Diego County Fire Chiefs' Association and the American Red Cross; The provision and underwriting of grants by SDG&E to support Volunteer Fire Fighters, CAL FIRE Public Information Officer Command Vehicles, Burn Institute programs, and the San Diego Kids Fire Safety Program;
- Fire-safety media campaigns in conjunction with the American Red Cross and local television station KUSI-TV; and,
- The "Prepare San Diego Partnership" and Sheltering Memorandum-of-Understanding executed by and with the American Red Cross;

SDG&E is a member of the California Utilities Emergency Association (CUEA), a collaboration between electric, natural gas, water and telecommunications utilities in California. CUEA serves as a point of contact for critical infrastructure utilities and the California Office of Emergency Services (Cal OES) and other governmental agencies before, during and after an event. CUEA also provides emergency response support wherever practical for electric, petroleum pipeline, telecommunications, natural gas, water and wastewater utilities.

C. Community Partnerships

SDG&E is proud to support non-profit organizations whose programs promote emergency preparedness and safety at home and in our communities. In 2012, SDG&E began providing funds to charitable organizations committed to regional and local emergency preparedness and fire safety, such as 2-1-1 San Diego, the American Red Cross, and the Burn Institute, plus dozens of volunteer fire departments, Community Emergency Response Teams, and Fire Safe Councils.

SDG&E provides regular communications to residents and businesses located in the FTZ and HRFA. These fire-safety and emergency communications include, but are not limited to:

- Customer education events, emergency preparedness symposiums for businesses, public participation meetings, and backup generator safety workshops;
- Informational and emergency preparedness mailings to customers in the HRFA;
- Educational advertising campaigns focusing on SDG&E's preparations for the fire season and the preparations SDG&E's customers should make for emergencies;
- Educational information disseminated through the Energy Notes newsletter distributed with customer billings;
- Distribution of a co-branded "newsletter" with the American Red Cross, the San Diego Office of Emergency Services, and the County Fire Chiefs Association;
- Distribution of the "pocket-Card", which provides formatted emergency information that easily folds and fits in an automobile glove box or emergency kit;
- Distribution of "refrigerator magnets" bearing important emergency information;
- The provision of weather information and system-outage status on SDGE.com;
- Dissemination of information regarding emergency-preparedness events via social media, such as Twitter and Facebook;
- Opt-in campaign offering customers electronic-mail access to safety checklists and fire-safety videos;
- Publication of information for SAFE San Diego Education and Outreach events in the community following an emergency.

In addition to routine outreach and communications, SDG&E intensifies its effort to communicate with customers when fire-threat conditions are elevated or extreme. SDG&E has instituted an early warning system advising customers that a Red Flag Warning has been declared by the National Weather Service and dangerously high winds are expected. SDG&E also opens communications with local water districts, telecommunications infrastructure providers, the San Diego County Office of Education, the San Diego County Office of Emergency Services, and the American Red Cross as soon as possible following the declaration of a Red Flag Warning. SDG&E assembles a team, including members from Business Services, SDG&E's meteorology department, and SDG&E's Electric Distributions Operations center, to provide updates on the status of the SDG&E system and weather conditions.

As alert conditions are elevated, SDG&E also contacts, directly and indirectly, Medical Baseline (MBL) customers, including life support and temperature sensitive customers. Under severe threats of emergencies, where SDG&E cannot make contact with these customers via our outbound-dialer system, SDG&E will send field personnel to make personal contact and, failing all else, to leave door hangers alerting the customer of the situation.

D. Fire Preparedness Website

SDG&E maintains a publicly accessible website focused on safety, including gas safety, electric safety, fire safety, tree safety, emergency preparedness, generator safety, and outage information. SDG&E Emergency Preparedness Brochures, pocket-Cards, radio spots, print advertisements, and social media postings via Facebook and Twitter, have been utilized to distribute and provide links to SDG&E's emergency preparedness and safety website:

http://www.sdge.com/safety/fire-safety/proactive-approach-fire-prevention

Additional fire-related websites supported and maintained by SDG&E are accessible using the following addresses:

- Emergency Preparedness web pages: http://www.sdge.com/safety
- Weather and Outage web pages: http://www.sdge.com/tools/windspeed-dashboard

E. Fire Mitigation Funds

In addition to providing various fire risk mitigation and preparedness grants as described above, SDG&E funds two fire-mitigation programs as a part of the Sunrise Power Link Project. These programs, known as the "Powerline Firefighting Mitigation Fund" and the "Defensible Space and Structure Hardening Grants Fund," are operated subject agreements with various firefighting agencies whose jurisdictions include lands along the Sunrise Power Link transmission corridor.

The Powerline Firefighting Mitigation Fund was used to provide a lump sum to each of the seven fire agencies with jurisdiction along the transmission line route. Each agency received $556,524, for a total disbursement of $3.9 million – these funds were used to purchase new fire trucks and communications equipment, increase fire patrols, and fund additional personnel during the fire season. The agencies receiving these funds include CAL FIRE, Federal Bureau of Land Management, County of San Diego, City of San Diego Fire & Rescue Department, Alpine Fire Protection District, Lakeside Fire Protection District, and the San Diego Rural Fire Protection District.

The Defensible Space & Structure Hardening Grants Program was implemented in 2012 and will remain in place as long as the Sunrise Power Link is in service. A Public Education and Outreach Program for eligible property owners includes a grant application website. The program provides funding for the creation and maintenance of defensible space around homes in close proximity to the Sunrise Power Link. This defensible space will bring those homes into with compliance with various fire codes so as to assist firefighters in minimizing structure and property damage. These funds may also be used to fire-harden structures by retrofitting rooftops with fire-resistant materials, installing fire shutters and double-pane windows, cave boxing, and removing and/or replacing wood fencing and/or decks. SDG&E annually provides $2.8 million (2008$) to fund the program.

VI. Wildfire Risk Reduction Model (WRRM)

A. Introduction

The SDG&E Wildfire Risk Reduction Model (WRRM) project involves the design, development and implementation of a scientific model and desktop software application to aid SDG&E staff in evaluating and prioritizing proposed asset hardening projects. The WRRM project team is a collaboration between SDG&E personnel and Technosylva Inc. (San Diego, CA) scientists and technical specialists. The complement of SDG&E Subject Matter Expertise (SME) with electrical distribution networks and Technosylva's fire science, modeling and software development is necessary to incorporate the requirements for the WRRM to meet SDG&E objectives. The following sections document the detailed design and development of the WRRM model and software including scientific components, algorithms, key data elements, and processing methods. The WRRM software encapsulates the modeling results into an operational tool that allows SDG&E engineers to quantify the risk reduction that will be achieved from different planned hardening projects.

1. Project Background

As part of the normal course of designing and maintaining its overhead electric system, SDG&E's engineers and designers endeavor to regularly analyze circuits to determine and offer hardening and rebuilding projects in order to reduce wildfire risk and increase reliability. These risk reduction projects vary widely in cost, complexity, duration and distance.

Each project is reviewed by a team of individuals and scheduled to be completed based on available capital as well as perceived risk that is based on a variety of factors and the associated ranking. However, through all this evaluation and risk perception SDG&E's engineers are unable to associate a specific percentage of fire related risk reduction gained by completing these projects. As such, SDG&E developed a risk reduction computer based modeling program that allows its engineers to evaluate and rank each project to determine the amount of fire risk reduction it would obtain as a result of completing any particular project.

This software model deliverable integrates leading edge fire science modeling to derive known and perceived risk measures that provide a rank of proposed electric overhead distribution hardening and re-build projects. The modeling outputs allow for a relative ranking of projects and quantify the amount of risk reduction expected for each project. The software operates on a standard Windows PC and supports operation by SDG&E engineers.

A range of different risk factors, inputs and values have been incorporated into the model including:

- Vegetation and fuels data,
- Weather and predictive services data,
- Historical fire occurrence and outage history,
- Fire behavior analysis and simulation models,
- SDG&E's electrical distribution network assets, conditions and characteristics,
- Subjective values-at-risk parameters, and
- Risk reduction projects.

SDG&E desired that the project be undertaken in a phase approach that built upon SDG&E and contractor subject matter expert's design and analysis of existing data, science and conditions. The custom software model leverages the information gathered to facilitate evaluation of multiple risk inputs and factors, with capabilities to refine and customize model parameters to meet priorities based on the evaluation of model results.

2. Project Objectives

The objective of the project was to develop a software program, referred to as the SDG&E Wildfire Risk Reduction Model (WRRM), that combines wildfire ignition likelihood, wildfire spread potential, and resource/asset vulnerability factors to estimate the potential for risk reduction, thereby assisting SDG&E staff in ranking proposed electric overhead distribution hardening and re-build projects.

The model outputs allow for a relative ranking of current risk as well as the expected absolute and percentage of risk reduction following individual project completion. The software program operates on SDG&E personal computers using IT standards and supports operations directly by SDG&E engineers to define hardening project assets and generate risk reports for those projects, providing the flexibility to adjust included assets to determine changes in potential risk reduction. The overall project objectives can be summarized as:

- Develop a model that will integrate key wildfire risk factors to quantify risk for assets
- Quantify the amount of risk reduction expected for individual hardening projects
- Support SDG&E personnel with ranking and prioritizing mitigation projects

3. Project Phases

The project workplan involved a series of logical phases and tasks that were implemented in an incremental manner, building upon achievements of previous phases to complete the design, development and implementation of the WRRM application. This approach leveraged technology and data investments already made by SDG&E. Project phases and tasks were:

- **Phase 1: Project Management**
  - 1.1 Project Initiation and Workplan Development
  - 1.2 Monthly Status Reporting
  - 1.3 On-going Phase Management
- **Phase 2: Wildfire Risk Reduction Model (WRRM) Design**
  - 2.1 Requirements Definition Workshops
  - 2.2 WRRM Design
- **Phase 3: Database Development**
  - 3.1 Data Compilation
  - 3.2 Database Development

- **Phase 4: Software Model Development**
  - 4.1 Ignition Submodel Development
  - 4.2 Fire Growth Potential Submodel Development
  - 4.3 Vulnerability Submodel Development
  - 4.4 Risk Reduction Summary Module Development
- **Phase 5: Software Testing and Scenario Outputs**
  - 5.1 Software Test Plan Development
  - 5.2 Scenario Testing
  - 5.3 Model Review & Software Refinement
  - 5.4 Development of Test Scenario Outputs
- **Phase 6: Documentation & Installation**
  - 6.1 Development of Software Manuals (User & Admin)
  - 6.2 Software Packaging
  - 6.3 Final On-site Installation
- **Phase 7: Final Presentation & Training**

Phase 1 addressed project logistics and administration and established the project management tasks to ensure the project was well-organized for the duration of the assignment. This included the initial kickoff meeting, project work plan development and on-going monthly status reporting/meetings and phase management.

Phase 2 leveraged close interaction and collaboration between the Technosylva team and SDG&E to define explicit model requirements that resulted in a robust model design. On-site interviews and workshops were used to solicit requirements and finalize the definition of model specifications. This included workflow, data, functional and system requirements. WRRM requirements were encapsulated in a formal model design document prior to any development occurring.

Phase 3 focused on compiling the input data required by the model and developing a database for use by the WRRM. This included integration with existing SDG&E data as well as compiling the best possible fuels, landscape, historical weather and assets data necessary for the model operation. The extraction of SDG&E GIS Asset data was a key task that required collaboration with SDG&E's GIS Group. A series of data processing steps were involved to create the WRRM input database from the SDG&E GIS Assets corporate data. These are documented in this report.

Phases 4 focused on the actual development of the submodels that comprise the Wildfire Risk Reduction Model. The models were implemented through custom software programs that facilitated use of GIS input data and parameter adjustment. This was done on a submodel basis with final integration of the models into a scenario-based architecture for evaluating risk reduction projects (i.e. the WRRM software).

Refinement of the model occurred throughout the software development and testing phases as model outputs were evaluated by the technical team, and adjustments made to incorporate local knowledge and model parameters. This was an iterative process that actively involved SDG&E personnel so that all aspects of SDG&E's requirements were addressed.

Phase 5 involved development of a software test plan, comprehensive testing, and the production of scenario based outputs. Test scenarios were defined by the FiRM group and used as the baseline for software testing and training. On-site training was held with SDG&E engineers to facilitate feedback on the software capabilities and refinements were made based on this feedback.

Phase 6 involved the development of the user manual and software administration manual, packaging of the software for installation, and final on-site installation and functional implementation testing. This involved addressing all technical IT requirements for ensuring the software operates within the SDG&E IT environment.

Phase 7 involved a final presentation to the SDG&E Fire Directors Committee and the SDG&E Executives to review the findings and results of the project.

4. Definition of Terms

The following table provides a definition of terms as they apply to the WRRM project. This reflects terms or acronyms that have specific implied meaning for use in a technical or subject matter context.

Table 7. Definition of terms for WRRM

Term/Acronym	Definition
Asset	Refers to a specific feature on the SDG&E electric utility infrastructure network, such as a pole, conductor, capacitor, transformer, fuse, etc.
Asset Class	A grouping of assets based on their characteristics, such as material type, size, age, that reflects a specific likelihood for equipment failure and wildfire ignition. All SDG&E assets are grouped into different *asset classes* so that different failure and ignition rates can be applied and used in the risk reduction model.
Asset Index	A six digit number used to delineate asset classes.
Burn probability	The probability of a wildfire burning into an area. This is sometimes referred to as a wildfire threat, probability of a fire occurring. As described in the WRRM design Burn Probability is the combination of numerous individual fire growth potential simulations to create an overall fire growth potential map, using only SDG&E Assets as possible ignition sources.
Conditional Impacts	The mean wildfire impact given that an equipment-related wildfire occurs at a specific location (also referred to as conditional risk). Conditional impacts is combined with ignition rate and wind factor characteristics to calculate the Expected Impacts. It is calculated for each asset and can be summed to quantify the conditional impacts for a specific hardening project.
Downfire	The location of a HVRA within the fireplain (fire growth from a specific ignition location)
Expected Impacts	The mean annual equipment-related wildfire impact after incorporating the likelihood of equipment failure and subsequent wildfire (also referred to as expected risk). This is a primary output of the WRRM model. It is calculated for each asset and can be summed to quantify the expected impacts for a specific hardening project.
Exposure	The placement of an HVRA in a hazardous environment – such as building a home within a flammable landscape.
Fireplain	The area where fire can spread to if ignited at a particular location. The fireplain is identified by either a deterministic simulation of fire growth, or through a stochastic simulation of fire growth. A fireplain represents the spread area commonly referred to as Time of Arrival – a raster representation of the fire spread, while Fire Perimeters is the vector format representation of the fire spread.
GIS Assets	The SDG&E GIS database of assets used as the source of potential ignitions for the WRRM.
Hardening Project	A series of field activities that may occur to change, repair, replace or affect asset equipment. The intent of these projects is to "harden" the equipment so that it more durable and less likely to fail. A project is a series of activities that may be combined together under a single work order or field visit for planning, budgeting and/or administrative management.
Ignition Likelihood	The probability that an asset may contribute to a fire ignition should equipment failure or external weather conditions under certain circumstances.

Term/Acronym	Definition
HVRA	Highly valued resources and assets, such as structures/homes, environmentally sensitive areas, etc.
Replacement Asset	The new asset class used to replace an existing asset class. Replacement assets have lower equipment failure rates and ignition rates than existing assets.
Risk Reduction	The expected risk over a 20 year planning horizon for an asset. This is the primary WRRM model output used to quantify risk reduction for an asset replacement. Risk reduction values are summed for assets in a specific hardening project to provide an overall risk reduction for that project.
Susceptibility	A measure of how easily a HVRA is damaged by wildfire of different types and intensities.
Values-at-risk	A general term that is commonly used to describe the HVRA and the risk assessed to them.
Vulnerability	A combination of Exposure and Susceptibility, vulnerability is the measure of potential (sometimes called conditional) impacts to HVRA from wildfires of different intensities
Wildfire hazard	A physical situation with potential for causing damage to resource or assets. Hazard is measured by two main factors – burn probability and intensity.
Wildfire risk	Overall measure of the possibility for loss or harm caused by wildfire. Risk is the combination of Hazard times the Vulnerability.

5. Supplemental Documents and Files

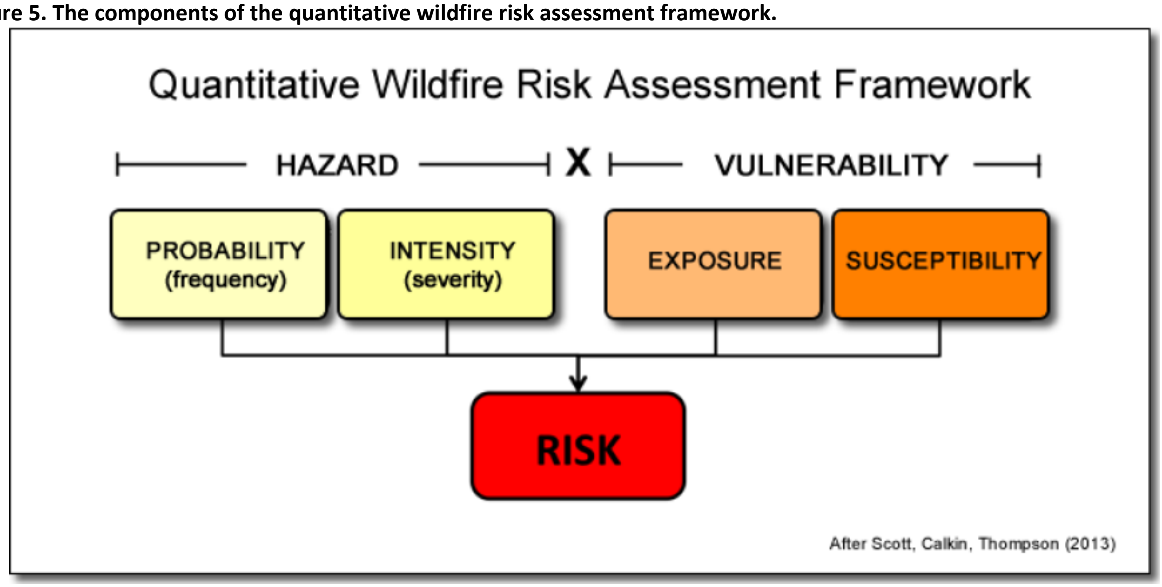
This design report is augmented with other documents used to develop the WRRM model design. These include:

- **WRRM Design Report** – a report that describes the initial model design developed in Phase 2 of the project. Numerous enhancements and refinements were implemented following this initial design as part of the model testing.
- **WRRM Model Algorithms XLS** – Excel table that provides the primary algorithms and calculations used in the model components.
- **WRRM Software** – a desktop Windows program that provides access to the WRRM model outputs for all assets in the SDG&E service territory. The software is provided as a run-time folder that does not require the conventional Windows installation process, thereby providing flexibility for simple installation and future updating with minimal effort or IT requirements. See Section D for a detailed description of the software architecture.
- **WRRM ArcMap MXD and File Geodatabase** – a large GIS dataset has been compiled from numerous sources, some internal to SDG&E and others external, to describe key data components described in this report. The data was compiled and analyzed in Phase 3 (Data Compilation & Database Development) of the project, and was essential for supporting model processing and development of risk outputs. The input data is provided in a separate ArcMap mxd document with accompanying File Geodatabase. Note this data is not required for the WRRM Software, however, it was key for the WRRM model to derive the fire growth and vulnerability outputs (specifically conditional impacts).
- **WRRM Project Final Presentations** – numerous PPT presentations provided to SDG&E management throughout the project. These presentations provide excellent detailed descriptions of the project progress and details. Much of the content of these presentations is incorporated into this report.

B. The Quantitative Risk Model Framework

The basis for a quantitative, landscape-scale framework for assessing wildfire risk to Highly Valued Resources and Assets (HVRAs) has been established for many years (Finney 2005, Scott 2006). The framework has been implemented across a variety of scales, from the continental United States (Calkin and others 2010), to individual states, counties and commercial operating areas (Buckley and others 2006, 2012, 2013), to a portion of a national forest (Scott, Thompson and others 2013). In this framework, wildfire risk at any point on the landscape is a function of two main factors—1) wildfire hazard, and 2) HVRA vulnerability.

Figure 5. The components of the quantitative wildfire risk assessment framework.



Wildfire hazard is a physical situation with potential for causing damage to vulnerable resources or assets. Quantitatively, wildfire hazard is measured by two main factors—1) burn probability (or likelihood), and 2) fire intensity (flame length, fireline intensity, or similar measure). These factors are simulated using fire behavior modeling software systems, such as Technosylva's Wildfire Analyst™ or similar software.

Vulnerability is also composed of two factors—1) exposure and 2) susceptibility. Exposure is the placement (or coincidental location) of an HVRA in a hazardous environment—for example, building a home within a flammable landscape. Some HVRAs, like critical wildlife habitat or endangered plants, are not movable; they are not "placed" in a hazardous environment. Still, their exposure to wildfire is the wildfire hazard where the habitat exists. Finally, the susceptibility of an HVRA to wildfire is how easily it is damaged by wildfire of different types and intensities. Some assets are fire-hardened and can withstand very intense fires without damage, whereas others are easily damaged by even low-intensity fire.

The framework described above characterizes wildfire risk across a landscape, without regard for a specific ignition location. We have used this framework with historical fire occurrence data to assess wildfire risk across landscapes, such as counties, operating areas, forests and states.

However, this approach, while valid for fire protection planning purposes, does not address the specific requirements of assessing wildfire risk associated with ignitions caused by electric utility networks (or other discrete ignition sources). For that, a modification of the standard landscape risk assessment method is required.

1. Characterizing Risk Associated with an Ignition Location (RAIL)

A customization of the risk framework is required when characterizing wildfire risk associated with specific ignition locations, such as an electrical utility network. Instead of characterizing wildfire risk where the expected losses occur, a RAIL analysis assigns those potential losses to the ignition location. This identifies which assets have the greatest risk.

The three main components of a RAIL analysis are:

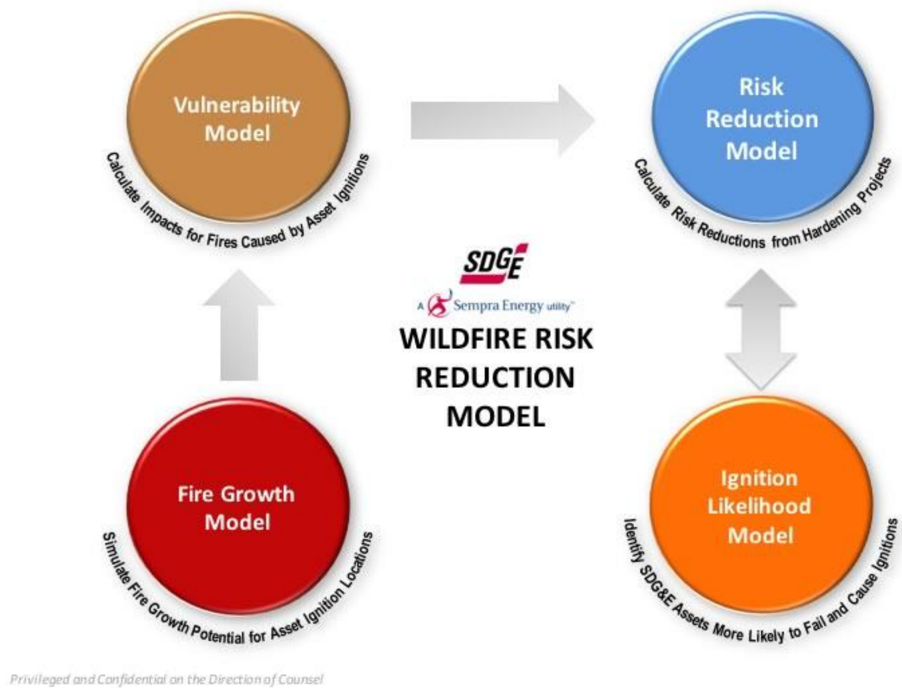
1. Ignition likelihood at the location
2. Fire growth potential of wildfires starting at the location, and
3. Vulnerability and value of resources and assets in the fireplain[11] surrounding the location

For the purpose of building the SDG&E Wildfire Risk Reduction Model (WRRM), these components must be assessed for each potential ignition location being considered, such as overhead electric distribution lines and related infrastructure (i.e. transformers, fuses, capacitors, etc.).

The following figure presents an overview of the WRRM model showing the main submodels and how they connect. The WRRM model culminates in the Risk Reduction Model component that integrates the Vulnerability Model outputs with tools to adjust the Ignition Likelihood (by replacing existing assets with new assets that have lower equipment failure and ignition rates). The Risk Reduction Model is encapsulated in the WRRM Software Application that brings all elements together.

[11] A "fireplain" is the area where fire can spread to if ignited at a particular location.

Figure 6. The WRRM submodels



A description of the submodel is provided below.

Ignition Likelihood

In the WRRM, electrical transmission and distribution equipment is the only ignition source under consideration. Existing data has been analyzed from various SDG&E systems to identify factors affecting the likelihood of ignition from electrical equipment in a segment of study. These include:

- Asset/equipment characteristics
    - Conductor type, size, age, number of splices, presence/absence of Communication Infrastructure Providers (CIPs), presence/absence of dynamic devices, and presence of dissimilar conduction type/size within the same span
    - Type, size, age and number of capacitors
    - Type and number of fuses
    - Type and age of transformers
    - Other circuit issues from field and operating personnel
    - Ignition risk assessed by SDG&E Fire Coordinators and FiRM program manager
- Landscape characteristics
    - Fuel availability near the assets
    - Height, density and species of trees near the equipment
    - Fuel moistures and other weather conditions
    - Wind factor—exposure to strong wind

Fire Growth Potential

The growth potential of fires originating at an ignition location is a function of the fire environment—fuel, topography, and weather—in the fireplain surrounding the ignition location. Factors considered in this component of the WRRM include:

- surface and canopy fuel (spatial)
- topography (spatial)

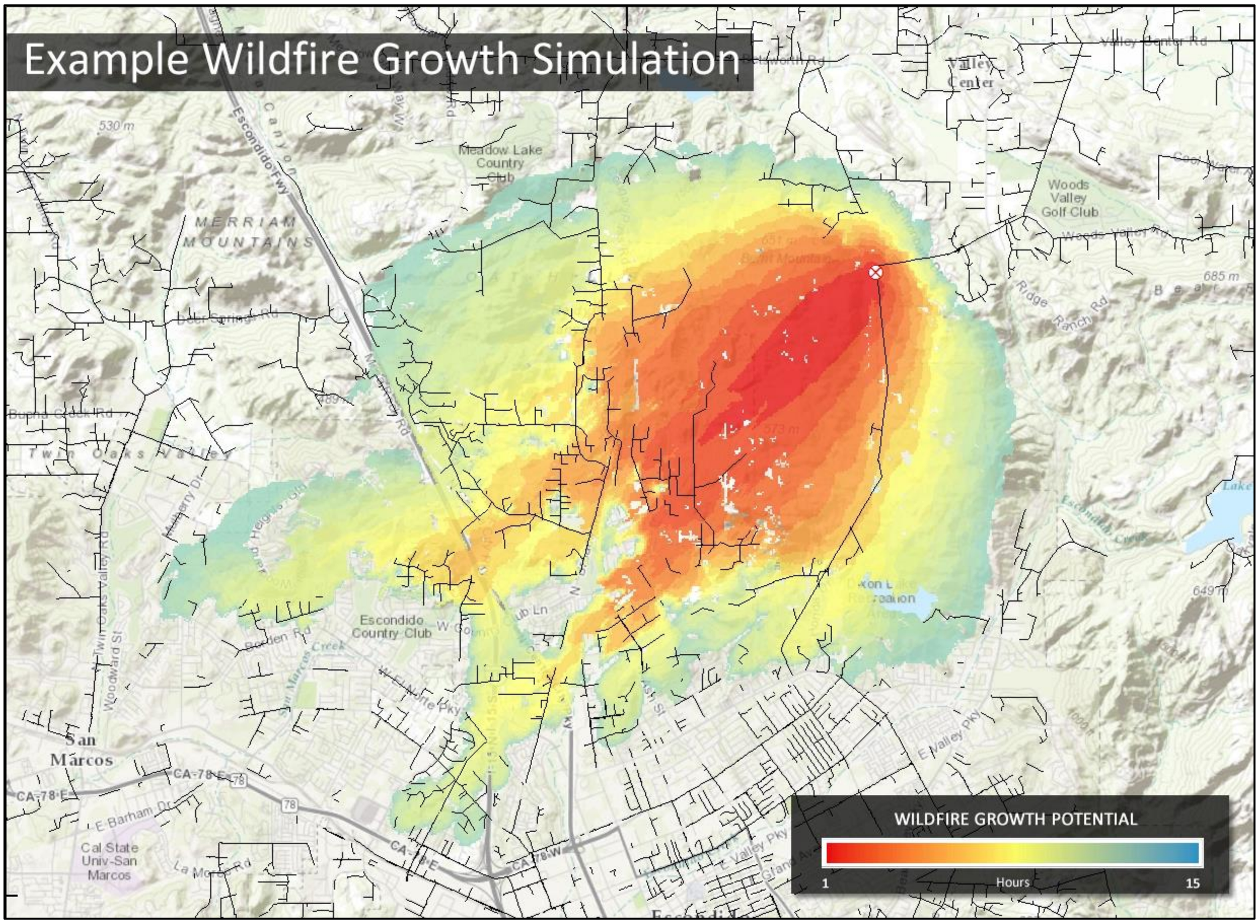
- wind speed and direction (spatial and temporal)
- fuel moisture (spatial and temporal)
- historical occurrence identifying time of data, typical weather conditions and duration
- level of encroachment into urban areas

The Fire Growth Potential component of the model relies on a fire growth modeling system, which consumes spatial and temporal information about the fire environment to simulate fire growth from a given ignition location for a specified period of time. Monte Carlo simulation of fire growth permits assessment of fire growth potential in the face of temporal variability in the fire environment. Depending on the specific risk analysis requirements, anywhere from a single simulation to potentially thousands of simulations are performed for each ignition location. The simulation output represents the potential spread of the fire given the specific input conditions (i.e. asset condition and characteristics, and weather conditions). Multiple simulations can also be combined to represent an overall probability of fire spread. This is often referred to as Burn Probability.

The following figure presents an example of a fire growth potential simulation for a possible ignition source on a utility feeder line. The fire spread output is presented as hourly fire perimeters for a fifteen (15) hour period using gradient shading. Fuels and landscape characteristics data are used in combination with weather and fuel moisture data as key inputs to derive the fire growth simulation. Accordingly, the simulation represents a fire growth potential for a specific set of input conditions (i.e. wind speed, wind direction, fuel moisture, temperature, humidity, etc.). In the map example shown below, the specific weather condition represents a strong wind from the NE resulting in a spread into urban areas to the south. Conductor lines are shown in black lines as reference. The specific asset ignition point is shown as ⊗.[12]

[12] The wildfire growth simulation was generated using the Technosylva Wildfire Analyst™ software product. This software was used to produce the wildfire growth simulations for the WRRM project.

Figure 7. Example fire growth simulation from a specific asset ignition.



Once all simulations are completed for all possible ignition source locations, they can be combined to derive a burn probability output that depicts the areas where fire will spread from all possible ignition source locations (total fire growth potential). This typically represents thousands or millions of simulations depending on the specific project requirements and capabilities.

Vulnerability

The vulnerability of HVRAs refers to the exposure and susceptibility of values-at-risk, such as structures/homes, critical facilities, timber, environmentally sensitive areas, etc. Exposure is the location of the HVRA with respect to wildfire hazard, while susceptibility refers to the level of impact (leading to loss) caused by wildfires of different intensities. For example, not all homes within a fire perimeter suffer the same level of impact. The level of impact will be a function of the fire intensity to which it was exposed and the condition of the home (or other resource value). Several different factors were considered for the WRRM implementation, however, SDG&E ultimately decided upon using the value of structures as the primary HVRA and measure of impact.

2. Wildfire Risk Reduction Model Computational Framework

Using the RAIL analysis described in the previous section we developed a wildfire risk reduction model that allows SDG&E to estimate the risk reduction potential of alternative hardening projects. The general computational framework for the WRRM is presented in this section, while the detailed model design and related algorithms are presented in the next section.

The wildfire risk—also called expected impact (*EI*)—associated with any overhead electric distribution asset is the product of the probability of equipment-related Ignition Probability (*IP*) for the asset and the Conditional Impact (*CI*) of a wildfire should one ignite at that location.

$$EI = IP * CI$$

CI is a function of both fire growth potential and asset vulnerability in the area surrounding the asset. *CI* is modeled by combining a custom implementation of deterministic fire growth models (Component 2 of the RAIL analysis) with geospatial data pertaining to the vulnerability and value of structures across the territory (Component 3). The fire growth simulation was conducted using the full distribution of historical weather conditions with corrections made for the relative probability of failure as a function of wind speed. A detailed description of the weather data selected for the WRRM is presented in Section C below.

SDG&E can accomplish risk reduction primarily by reducing *Ignition Probability* (by hardening or rebuilding electric distribution equipment; see Component 1). The amount of risk reduction associated with the project (*RR*) is estimated as

$$RR = EI_{Cur} - EI_{Replace}$$

Where *EIcur* is the expected impact for the current asset and *EIpost* is the expected impact for the replacement asset. Because equipment modification does not change *CI*, *RR* can be expressed more as

$$RR = CI * (IP_{Cur} - IP_{Post})$$

Ignition Probability is calculated as an annual rate, so *RR* is inherently an annualized result that is achieved not just in one year, but for many years into the future after the hardening project. To account for this multi-year benefit, a 20-year planning horizon was applied to calculate the 20-year risk reduction as

*CI * ((1-(1-(CurrentIgnitionRate))^PlanningHorizon)-(1-(1-(ReplacementIgntionRate))^PlanningHorizon))*

This calculation does not use discount or inflation rates, which implies that the discount rate applied to future risk reduction benefits is exactly offset by an increase in the cost of wildfire impacts in the future (due to increases in rebuilding costs or increases in building exposure, for example).

A mitigation project may consist of several equipment modifications along a segment, so a project-level measure of risk reduction is the sum of calculated *RR* values for all equipment changes in the project. Further, this risk reduction is accrued for each time period associated with P_i. If P_i is measured or indexed on an annual basis (probability per year), then the present value of annual B_{seg} can be calculated and compared to the present value of the project cost.

The benefit of this framework is that it accommodates consideration of potential wildfire impacts (or consequences) in their native units of measure, not just relative measures of risk reduction. This provides opportunities to extend the risk reduction analysis to consider metrics for calculating *dollar exposure* and Return on Investment. These are common metrics used in fire management planning for fuel treatment planning and analysis. They could be extended to infrastructure hardening projects.

The following section presents the WRRM model design with detailed descriptions of the risk framework components.

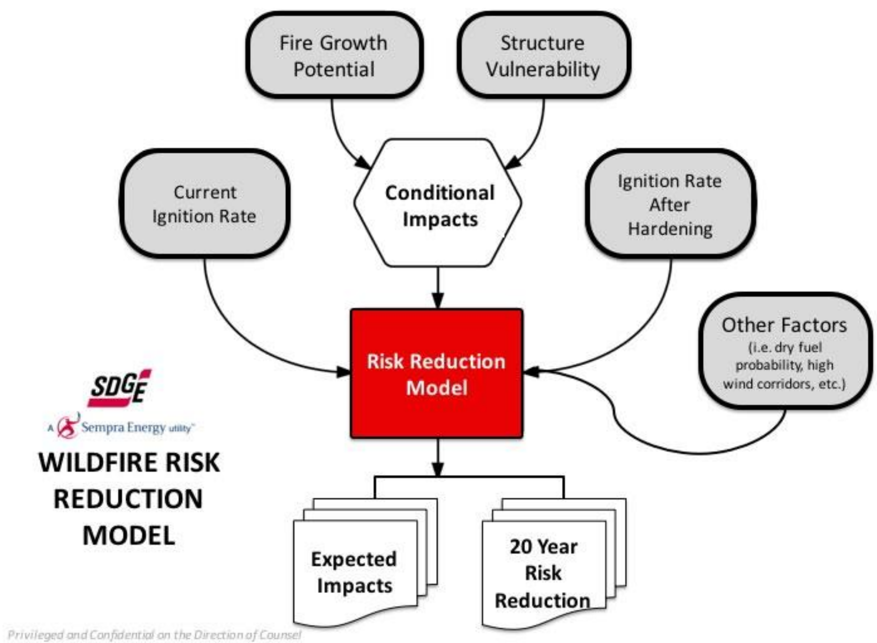
C. Detailed Description of WRRM Components

The foundation of the WRRM is an assessment of potential exposure to costs and losses associated with a wildfire caused by failure of an electric power distribution asset. More specifically, the WRRM compares the current exposure with the exposure if a specified asset hardening project were undertaken. That analysis requires an assessment of the potential for electric power distribution equipment to cause wildfires that result in damage to highly valued resources and assets (HVRAs), such as homes and other buildings.

The WRRM design is based on a RAIL analysis, which characterizes the wildfire Risk Associated with an Ignition Location. Instead of characterizing wildfire risk where the expected losses occur (where the homes are), a RAIL analysis assigns those potential losses to the ignition location (and to the electric power distribution asset that potentially caused the ignition). Each electric power distribution asset in the system is a potential ignition location.

The WRRM assesses the three model components – 1) ignition likelihood, 2) fire growth potential and 3) vulnerability - at the location of each electric power distribution asset being considered. The Fire Growth Potential and HVRA Vulnerability components are combined to determine the exposure at a particular location if a wildfire should occur there. This "conditional" exposure is then combined with the likelihood of ignition—both current and after a hardening project—as determined in the Ignition Likelihood component (Figure 8). The WRRM then produces results quantifying the amount of risk reduction accomplished by the project.

Figure 8. The detailed WRRM model components.



The Fire Growth Potential and Structure Vulnerability components of the WRRM combine to determine the Conditional Impacts at the potential ignition location (given that a wildfire occurs). The WRRM then combines the Conditional Impacts with the likelihood of an ignition—current and after hardening—to calculate the Expected Impacts and quantify the amount of Risk Reduction accomplished. Risk Reduction is reflected over a 20 year planning horizon.

Additional details regarding each of the three WRRM components is provided in the following sections.

1. Ignition Likelihood

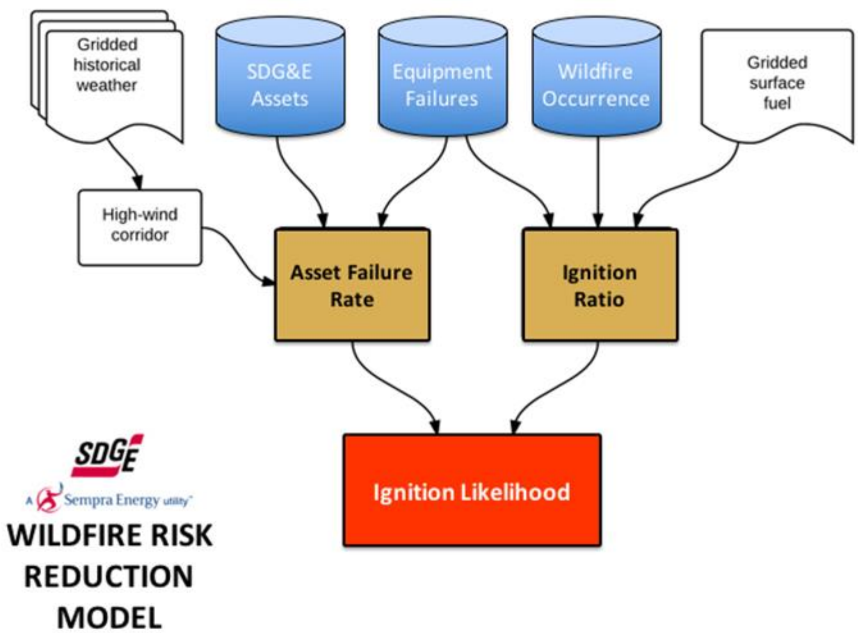
Ignition likelihood for each electric power distribution asset under consideration is estimated by an analysis of the:

1. Failure rate of assets present in the system, and the
2. Ratio of wildfire ignitions to asset failures.

The ignition likelihood component of the WRRM is driven by asset, asset failure, wildfire occurrence, and weather databases provided by SDG&E, and by an ancillary surface fuel data obtained or developed by Technosylva. The following figure presents the following information used to derive equipment failure rates and ignition rates:

- SDG&E asset geodatabase (GIS)
- Asset-failure database and other SDG&E related databases that help to identify the characteristics of asset equipment that has historically failed and/or caused fire ignitions. This includes the following SDG&E databases:
    - Wire Down & RIRAT Analysis (FiRM)
    - Equipment Failures
    - Outage Reliability
    - Corrective Maintenance Program
- Wildfire occurrence database (SDG&E-caused ignitions)
- Gridded historical weather (to identify high-wind portions of the landscape)
- Gridded surface fuel (to identify asset locations not capable of igniting a wildfire due to a non-burnable land cover)

Figure 9. Data used to determine the likelihood of a wildfire ignition for a specific asset.



The GIS asset geodatabase identifies all of the electric power distribution assets under consideration. This includes conductors, poles, capacitors, fuses, transformers and dynamic protection devices (DPD). Each asset is a potential ignition location.

Identifying Asset Classes More Prone to Igniting Fires

Working with SDG&E subject-matter experts (SMEs), each asset was characterized to facilitate the identification of "asset classes." This characterization uses factors identified by SDG&E as potentially affecting ignition likelihood, such as asset type, age, material, its proximity to wildland fuel, whether it is within a high-wind corridor, and so on. Assets were classified into groups based on similar characteristics that defined their propensity for possible equipment failure and causing fire ignitions.

An analysis of various SDG&E databases was conducted to identify the asset characteristics that best define the likelihood for equipment failure. This information, along with SDG&E expert opinion, was used to define the asset classes. This definition was the first step for grouping similar assets together for use in the model. Once the asset classes were defined they were assigned different failure rates and ignition rates.

As an example, let's consider Primary Overhead Conductors, considered a primary source for fire ignitions. Based on information provided by the FiRM program results and Technosylva's analysis of other SDG&E datasets, such as Equipment Failures, Outages and Reliability, etc., the different asset classes identified for the Primary Overhead Conductor asset are:[13]

1. #6 Strand CU
2. #4 Strand CU
3. #6 Solid CU
4. #2 – 2005
5. #1/0 CU
6. All other conductors

The characteristics of the Conductor type, material, and size form the basis of the different asset classes. Assets of a particular material, type and size are then defined by different length categories and age categories, such as:

Age (years)

- Greater than 50 years
- 40 – 50
- 30 – 40
- 0 - 30

Span Length (feet)

- Greater than 1000
- 500 – 1000
- 300 – 500
- 0 - 300

Conductors that are older and a greater span length are considered a greater risk for possible failure and wire down events, and possibly igniting fires. Other characteristics are then considered including:

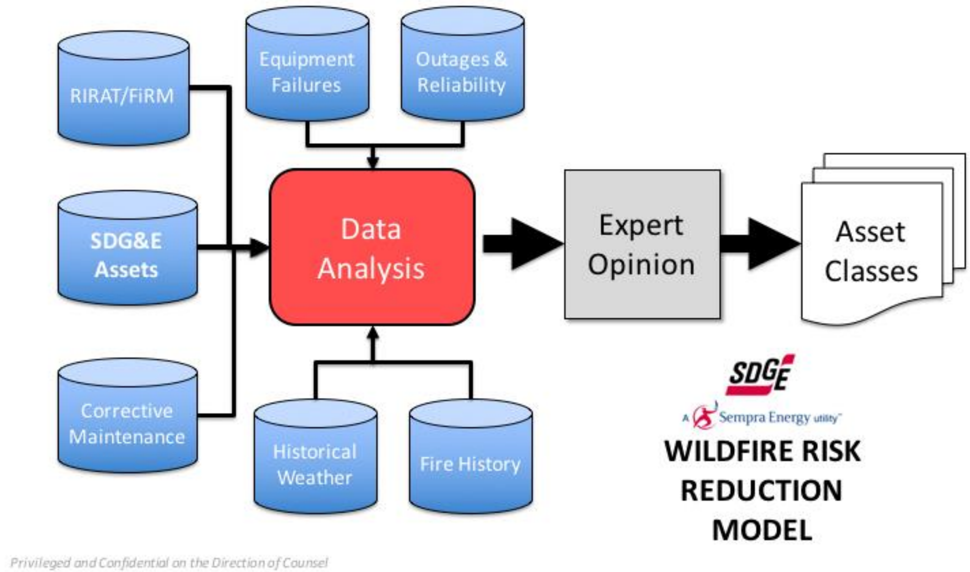
- Does the conductor span have splices?
- Is there a dissimilar conductor type and size within a span?
- Is there a Communication Infrastructure Provider on the conductor?
- Is the conductor protected by a dynamic protection device?

If Conductors also match these criteria they would be considered an even greater source for fire ignition. This example uses Conductors as a particular asset, however, the definition of asset classes is also being undertaken for other SDG&E asset types, such as capacitors, poles, fuses and transformers – all possible sources for fire ignition.

Once all the assets in the service territory were categorized into asset classes they were assigned a failure rate and ignition rate. Initial failure rates and ignition ratios were assigned based on information obtained from the SDG&E RIRAT process in the Fire Risk Mitigation Program and supplemented by information from other SDG&E databases such as Equipment Failures, Outages and Reliability, and Corrective Maintenance Program. Full parameterization of the asset classes for the ignition likelihood model was completed by SDG&E subject matter expert opinion and feedback. The following figure shows the information analyzed to identify the different asset classes for the WRRM.

[13] Note that similar asset classes are also defined for fuses, poles, transformers, capacitors, and DPDs.

Figure 10. Analysis process used for determining Asset Classes.



It is important to note that the analysis of several SDG&E internal databases, such as the Outages and Reliability database and the Equipment Failures database, substantiated the findings of the FiRM program analysis results. That is, equipment failures and fire ignitions tend to occur on assets with specific characteristics and through on-going analysis and tracking of these failures and assets steps can be taken to mitigate ignitions and costly wildfires.

Appendix A presents the table of different asset classes identified for the WRRM. It includes fields that describe the unique attributes of each as well as equipment failures and ignition rates.

Calculating Ignition Likelihood

Assets were classified into asset classes. An asset class is a grouping of assets of similar type, size, material, age, etc. All assets within an asset class are assumed to have the same Relative Failure Rate (RFR). Ignition likelihood for each asset class (*i*) is calculated as a function of the failure rate of the asset and the ratio of fire ignitions to asset failures for each asset class. An asset class (*i*) consists of an asset type, material, age, etc. as determined by SDG&E SMEs in on-site and web meetings (and confirmed by analysis of the various SDG&E databases – GIS Assets, Equipment Failures, FiRM Wire Down Analysis, Outages, etc.).

$$IgnitionProbability = Relative\ Failure\ Rate * Igniton\ Ratio$$

where

- *Ignition Probability* is the ignitions per asset per year
- *FailureRate* is the number of failures per asset per year
- *IgnitionRatio* is the ratio of fire ignitions to failures

The *FailureRate* and *IgnitionRatio* are estimated by linking the datasets shown in Figure 9. *FailureRate* is the number of failures in the database divided by the total number of assets in the system divided by the number of years in the failure database. *IgnitionRatio* is the number of wildfire ignitions for an asset class divided by the number of failures in the class. Only the failures that occurred over or near burnable land cover are included in the denominator of this calculation. The estimation of *IgnitionLikelihood* is calculated in this manner to take advantage of the robust failures database rather than rely solely on the wildfires database.

To illustrate this, let's review an example for a hypothetical asset within a particular asset class—a conductor span of #6 Cu strand, >300 ft. span length, 30-50 years of age and located across a landscape of burnable fuels (Figure 11). Assets with these characteristics have been defined by analyzing the SDG&E wire down analysis, equipment failures and outages databases. In this example,

- SDG&E Primary Overhead Conductors are shown as thin black and red lines;
- Conductor assets that match the criteria above between 300 and 500 feet span are in BLUE, and
- Conductor assets that match the criteria above greater than 500 feet in length are in RED.

This map identifies where assets matching the criteria are located:

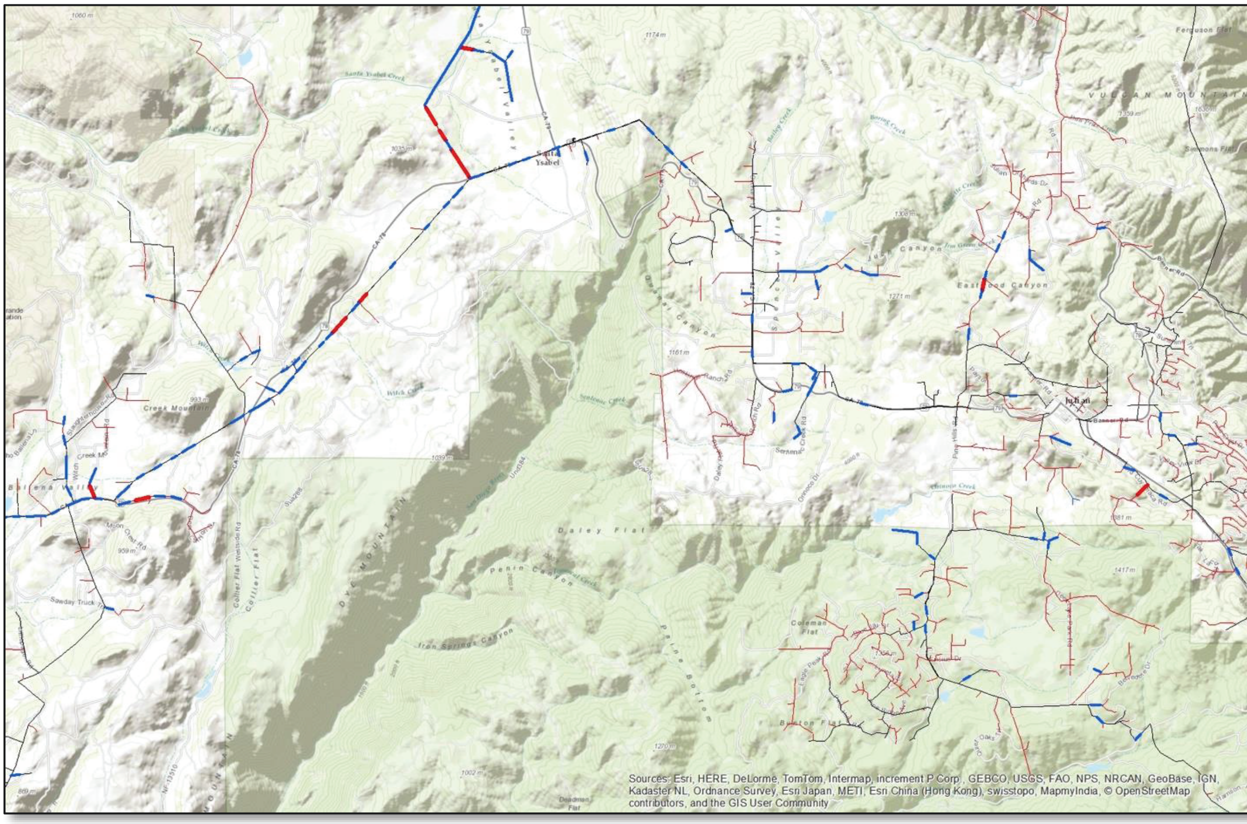


Figure 11. Example of SDG&E assets that match specific ctriteria (material, type, age, size) prone to equipment failure and/or outages.

The SDG&E GIS asset geodatadabase, in combination with the weather and fuel databases, indicates the number of assets in the system by type, material, age and other factors identified by SDG&E subject-matter experts as potentially impacting equipment failure or ignition. A query of the various databases finds that there are (hypothetically) 27,566 spans in this asset class in the service territory. Over the ten years of the failure database, let's say there were 46 failure events for this asset class. The annual *FailureRate* for that asset class is then

$$FailureRate_i = \frac{46/10}{27{,}566} = 0.000167\ failures\ per\ year\ per\ span$$

The number of failures per span per year is also the annual probability of failure for an individual span of that class. To alleviate the challenge with looking at very low probabilities (lots of decimal places), we can express this probability as the number of failures per year per million assets.

$$FailureRate = 0.000167 * 1000000 = 167\ failures\ per\ year\ per\ million\ spans$$

The *IgnitionRatio* factor of the ignition likelihood calculation accounts for the likelihood of fire ignition given that a failure occurs over flammable vegetation. Of the 46 failures, let's say that only 12 were associated with flammable vegetation. The remaining 34 ignitions occurred over non-burnable land cover, such as urban or non-burnable agricultural areas, and thus were not capable of igniting a wildfire. Finally, let's say there were 5 wildfires associated with these 12 failures. The *IgnitionRatio* is calculated as

$$IgnitionRatio = \frac{5}{12} = 0.417$$

In other words, in this hypothetical example, 41.7 percent of the failure events associated with flammable vegetation resulted in a wildfire.

Finally, the *IgnitionLikelihood* for the asset class is the product of the *FailureRate* and the *IgnitionRatio* (assuming the asset is associated with burnable land cover; if not, the *IgnitionLikelihood* is zero). In this hypothetical example, the *IgnitionLikelihood* is

$$IgnitionLikelihood = 0.000168 * 0.417 = 0.0000695\ fires\ per\ span\ per\ year$$

This estimate of the number of fires per span per year is also the annual probability of a fire start per span. An alternative way to express this *IgnitionLikelihood* is as the number of fires per year per million assets. This is calculated by multiplying the calculated *IgnitionLikelihood* by 1,000,000. In this example, that is 69.5 fires per million spans per year.

The WRRM will estimate the *FailureRate*, *IgnitionRatio* and overall *IgnitionLikelihood* for each asset class identified by SDG&E subject matter experts. However, due to an insufficient number of records in the failures and wildfire databases, the technical team was unable to make reliable estimates for all fully refined asset classes. Therefore, a thorough critique and adjustment and grouping of these data-driven failure and ignition rates by SDG&E subject-matter experts was required. The final tabulation of failure and ignition rates was calibrated during this critique and adjustment such that the rates produce the observed mean annual number of failures in the system.

The above process produced an ignition likelihood value for each asset class (ignitions per year per asset). This table of ignition likelihood forms the basis of the WRRM model itself. Reduction in ignition likelihood due to a hardening project will depend on the number of assets in each asset class to be replaced and what they are being replaced with. The basic assumption is that hardening projects will either repair or replace existing assets with newer assets that are less prone to failure and possible ignition, thereby reducing the ignition likelihood for those assets in the system.

2. Fire Growth Potential

The fire growth model defines where possible ignitions will spread across the landscape. This definition of spread is critical for defining vulnerability and potential impacts due to these wildfires. The risk associated with each possible ignition provides the basis for evaluating the best opportunities for reducing risk by implementing hardening projects. This section describes the elements of the fire growth model component of WRRM.

The fire growth potential component of the WRRM is driven by stochastic wildfire simulations based on datasets related to the three components of the fire behavior triangle—fuel, weather and topography (Figure 12).

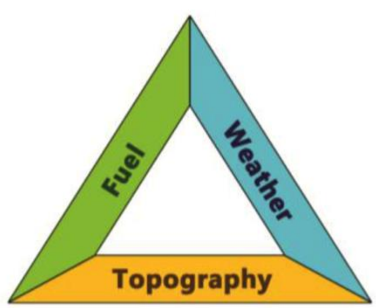


Figure 12. The fire behavior triangle comprises the three elements of the fire environment - fuel, weather, and topography.

The datasets used in the Fire Growth Potential component include:

- Surface fuel model characteristics
- Topography (slope and aspect)
- Historical weather geodatabase (wind speed/direction, fuel moisture, ERC—on a 4 km grid)

These three factors vary across the SDG&E service territory, so the growth potential of wildfires starting in different parts of the territory also varies. Some locations within the territory can produce larger and higher-intensity wildfires than others, so the impacts of a wildfire depends on where the ignition occurs.

To create the simulation framework to calculate the fire growth potential, three basic inputs need to be defined:

> **What is going to burn?** (Vegetation described as surface fuels models)
> For this component, an enhanced version of the surface fuels originally developed in the 2010 San Diego County Wildfire Risk Assessment project was used. This dataset represents the currently most accurate available fuels data source.
>
> **What are the conditions during the fire?** (Fire Weather percentiles)
> The 4-km gridded historical weather data provided by SDG&E provides the foundation for the weather component of the fire environment. This data source provides a rich dataset that can be mined to extract specific weather conditions based on detailed historical observations. The availability of such a rich weather dataset is unusual for wildfire risk assessment and, as such, will provide a substantial benefit in accuracy for the fire growth simulation outputs, compared to other weather data sources.
>
> **When did the fires happen?** (Incident parameters such as start time and duration)
> The fire history dataset provided by SDG&E has been analyzed to provide initial parameters that define the most common time (months/days/time of day) when fires occur, as well as the duration and weather conditions for when wildfires are ignited from SDG&E assets. This data was used to guide the conditions used for the fire growth simulations.

The following sections provide a detailed description of these primary components of the fire growth model. In addition, a description of the processing methods for the fire growth model is included.

Surface Fuel Models

Surface fuel model data is used as the primary input to predict the spread of wildfire and its behavior conditions. Fuels models are a GIS map that identifies specific fuels classes that are characterized by specific behavior conditions and response to fire. These models synthetize the vegetation characteristics in terms of different variables that allow the models to estimate the rate of spread, flame length and fireline intensity of a fire under certain weather conditions. An accurate definition of surface fuels in concert with weather conditions data, including fuel moistures, is critical to obtain accurate fire growth simulations. This provides the foundation for determining vulnerability and risk in the WRRM.

The fuel model classification scheme that is the standard approach for fuels mapping was developed by Joe Scott and Robert Burgan in 2005.[14] It is a set of 40 dynamic fuel models, describing how different types of vegetation will behave based on certain landscape conditions. The following table describes the fuel model names with a brief description. Fuels are defined in different categories to match typical vegetation conditions, i.e. grass, grass-shrub, etc. A standard color has been assigned to each fuel model by Technosylva to ensure consistency when viewing fuels on maps. This matches the map examples in the report.

Table 8. Description of Scott & Burgan surface fuel models.

Surface Fuel	Description
Grass Fuels Type Models (nearly pure grass and/or forb type)	

[14] Please refer to Appendix B for the references for the description of the Scott & Burgan fuel models.

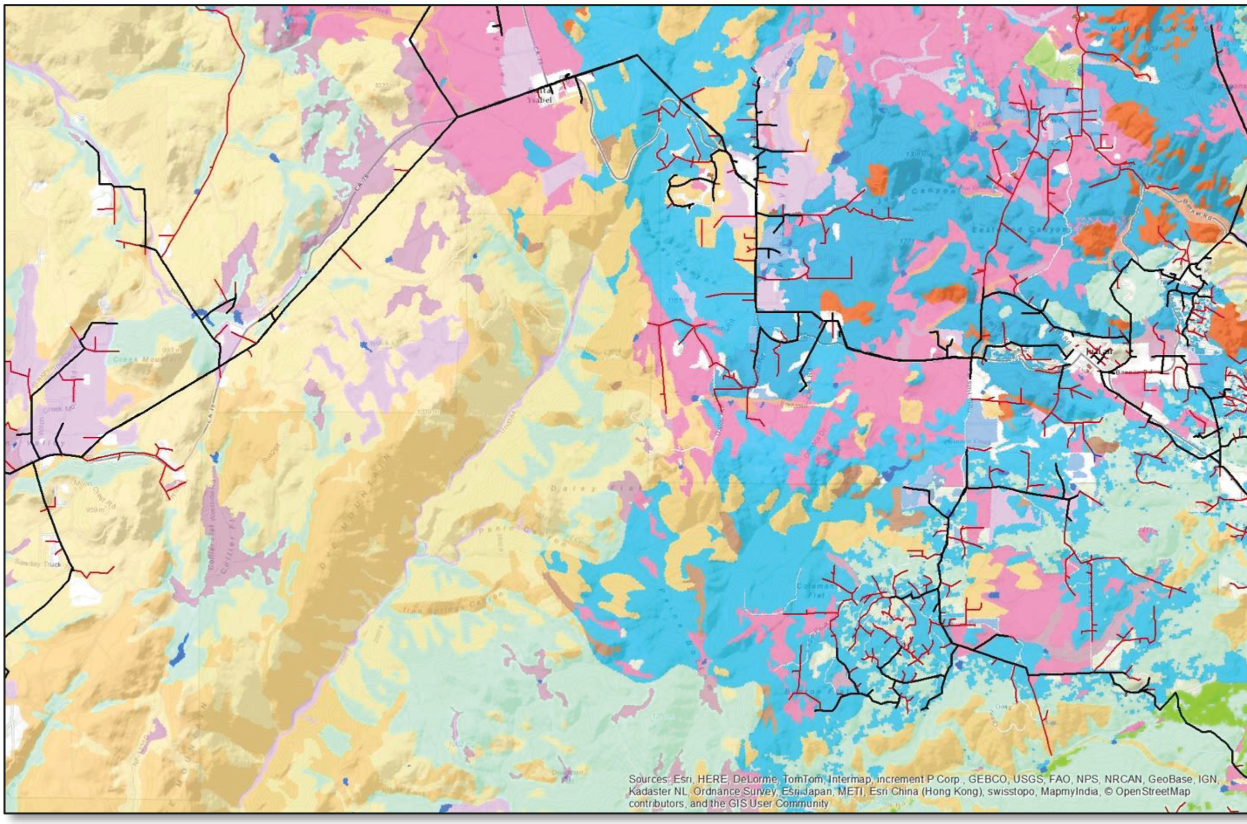
Surface Fuel		Description
	GR01	Grass is short, patchy, and possibly heavily grazed. Spread rate moderate; flame length low.
	GR02	Moderately coarse continuous grass, average depth about 1 foot. Spread rate high; flame length moderate.
	GR03	Very coarse grass, average depth about 2 feet. Spread rate high; flame length moderate.
	GR04	Moderately coarse continuous grass, average depth about 2 feet. Spread rate very high; flame length high.
	GR05	Dense, coarse grass, average depth about 1 to 2 feet. Spread rate very high; flame length high.
	GR06	Dryland grass about 1 to 2 feet tall. Spread rate very high; flame length very high.
	GR08	Heavy, coarse, continuous grass 3 to 5 feet tall. Spread rate very high; flame length very high.
	GR09	Very heavy, coarse, continuous grass 5 to 8 feet tall. Spread rate extreme; flame length extreme.
Grass-Shrub Fuel Type Models (mixture of grass and shrub, up to 50 percent shrub coverage)		
	GS01	Shrubs are about 1 foot high, low grass load. Spread rate moderate; flame length low.
	GS02	Shrubs are 1 to 3 feet high, moderate grass load. Spread rate high; flame length moderate.
	GS03	Moderate grass/shrub load, average grass/shrub depth less than 2 feet. Spread rate high; flame length moderate.
	GS04	Heavy grass/shrub load, depth greater than 2 feet. Spread rate high; flame length very high.
Shrub Fuel Type Models (Shrubs cover at least 50 percent of the site, grass sparse to nonexistent)		
	SH01	Low shrub fuel load, fuelbed depth about 1 foot; some grass may be present. Spread rate very low; flame length very low.
	SH02	Moderate fuel load (higher than SH01), depth about 1 foot, no grass fuel present. Spread rate low; flame length low.
	SH03	Moderate shrub load, possibly with pine overstory or herbaceous fuel, fuel bed depth 2 to 3 feet. Spread rate low; flame length low.
	SH04	Low to moderate shrub and litter load, possibly with pine overstory, fuel bed depth about 3 feet. Spread rate high; flame length moderate.
	SH05	Heavy shrub load, depth 4 to 6 feet. Spread rate very high; flame length very high.
	SH06	Dense shrubs, little or no herb fuel, depth about 2 feet. Spread rate high; flame length high.
	SH07	Very heavy shrub load, depth 4 to 6 feet. Spread rate lower than SH05, but flame length similar. Spread rate high; flame length very high.
	SH08	Dense shrubs, little or no herb fuel, depth about 3 feet. Spread rates high; flame length high.
	SH09	Dense, finely branched shrubs with significant fine dead fuel, about 4 to 6 feet tall; some herbaceous fuel may be present. Spread rate high, flame length very high.
Timber-Understory Fuel Type Models (Grass or shrubs mixed with litter from forest canopy)		
	TU01	Fuelbed is low load of grass and/or shrub with litter. Spread rate low; flame length low.
	TU02	Fuelbed is moderate litter load with shrub component. Spread rate moderate; flame length low.

Surface Fuel		Description
	TU03	Fuelbed is moderate litter load with grass and shrub components. Spread rate high; flame length moderate.
	TU04	Fuelbed is short conifer trees with grass or moss understory. Spread rate moderate; flame length moderate.
	TU05	Fuelbed is high load conifer litter with shrub understory. Spread rate moderate; flame length moderate.
Timber Litter Fuel Type Models (dead and down woody fuel litter beneath a forest canopy)		
	TL01	Light to moderate load, fuels 1 to 2 inches deep. Spread rate very low; flame length very low.
	TL02	Low load, compact. Spread rate very low; flame length very low.
	TL03	Moderate load conifer litter. Spread rate very low; flame length low.
	TL04	Moderate load, includes small diameter downed logs. Spread rate low; flame length low.
	TL05	High load conifer litter; light slash or mortality fuel. Spread rate low; flame length low.
	TL06	Moderate load, less compact. Spread rate moderate; flame length low.
	TL08	Moderate load and compactness may include small amount of herbaceous load. Spread rate moderate; flame length low.
	TL09	Very high load broadleaf litter; heavy needle-drape in otherwise sparse shrub layer. Spread rate moderate; flame length moderate.
Slash-Blowdown Fuel Type Models (activity fuel/slash or debris from wind damage)		
	SB01	Low load activity fuel. Spread rate moderate; flame length low.
	SB02	Moderate load activity or low load blowdown. Spread rate moderate; flame length moderate.
	SB03	High load activity fuel or moderate load blowdown. Spread rate high; flame length high.
Non-burnable Fuel Type Models (insufficient wildland fuel to carry a wildland fire under any condition)		
	NB01	Urban or suburban development; insufficient wildland fuel to carry wildland fire. Includes roads.
	NB03	Agricultural field, maintained in nonburnable condition.
	NB08	Open water
	NB09	Bare ground

In the SDG&E service territory only certain fuels exist and need to be considered. For example, the predominant vegetation in the county is grass and shrubs (particularly chaparral), while timber is mostly located in east county and National Forests. Accordingly, we are primarily concerned with surface fuels and less concerned with canopy fuel characteristics. There are several additional data sets that are required to properly analyze canopy fire conditions. These datasets augment the surface fuels data and will be used in the project, however, they are less important for analyzing fire behavior in most of the SDG&E service territory given the predominant grass and shrub fuels.

The following figure shows the surface fuels for an example area. This detailed map shows the level of resolution of the fuels data relative to SDG&E assets. Conductors are shown in black and red lines as reference. Fuel model classes match the colors shown in Table 8.

Figure 13. Surface fuel model classes for the example area with SDG&E assets overlaid.



Several different possible data sources exist for surface fuels data in the SDG&E service territory. These include the federal LANDFIRE program, CalFIRE Fire Risk Assessment Program (FRAP), US Forest Service regional data, and the most recent 2010 San Diego Wildfire Risk Assessment (SD WRA).[15] Based on an evaluation of these different data sources we believe the 2010 SD WRA fuels data is the best source. These fuels are the highest resolution (10 meter vs 30 meter for other sources), and have been derived from the County Land Use and Planning Department vegetation dataset.[16] The LANDFIRE and CalFIRE fuels suffer from certain deficiencies, including the lack of updating to reflect fires and urban growth over the past several years, and a lack of field survey verification.

In addition, Technosylva recently completed a detailed fuels mapping project for Marine Corps Base Camp Pendleton (MCP) as part of a comprehensive wildfire risk assessment project. This project utilized advanced remote sensing and image processing techniques combined with 1,600+ field surveys to define a robust surface fuels dataset and classification approach. Since the fuels at MCP closely match fuels found across San Diego County, the methods and knowledge were leveraged to conduct a rapid refresh of the 2010 SD WRA fuels dataset. This addressed some minor issues for urban growth and recent fire disturbances that have changed fuels in specific areas and brought the data up to date for 2014. While not totally comprehensive, this provided the best possible fuels data source for the WRRM project. In particular, we focused on using Landsat 8 satellite imagery with image processing techniques to produce

[15] Note that the SD risk assessment was undertaken by the WRRM Technosylva staff and accordingly we have an intimate knowledge of the different fuel data sources and their pros and cons.

[16] Methods were developed by Joe Scott and the Technosylva team in 2010 to crosswalk current SD LUPD vegetation classes into surface fuels classes. This approach provides the flexibility of defining a fuels resolution that is desired as well as taking advantage of annual updates of the vegetation data by SD LUPD.

fuels data updates in areas around the SDG&E asset network. This ensured these areas were accurate and up-to-date since these will be the primary areas of initial fire spread (for fires ignited by SDG&E assets).

In addition, this dataset was produced at a 10 meter (m) spatial resolution ensuring that the fire behavior analysis can accurately describe the conditions expected in the narrow pencil canyons in the county that are often carriers of fire. The LANDFIRE and CalFIRE fuels datasets at 30m spatial resolution do not adequately accommodate this key requirement.

The rapid refresh of the 2010 SD WRA fuels was completed as part of the Phase 3 (Database Development) in the WRRM project. The following figure presents the updated surface fuels for the SDG&E service territory (Figure 14). Fuel model classes match the colors shown in Table 8.

Figure 15 demonstrates the improvement obtained by conducting the rapid refresh for the 2010 SD WRA fuels data to reflect 2014 conditions. The map on the left shows the 2010 existing fuels layer at 10 m resolution. The map in the center shows the actual orthophoto imagery for the area as reference, and the map on the right shows the new fuels layer created in the rapid refresh process. SDG&E assets are shown as reference on each map. Note the updated accuracy for specific areas particularly near SDG&E assets. This increased spatial accuracy and fuels delineation resulted in more accurate fire behavior modeling outputs for the fire growth model component.

Figure 14. Surface fuel models for SDG&E service territory.

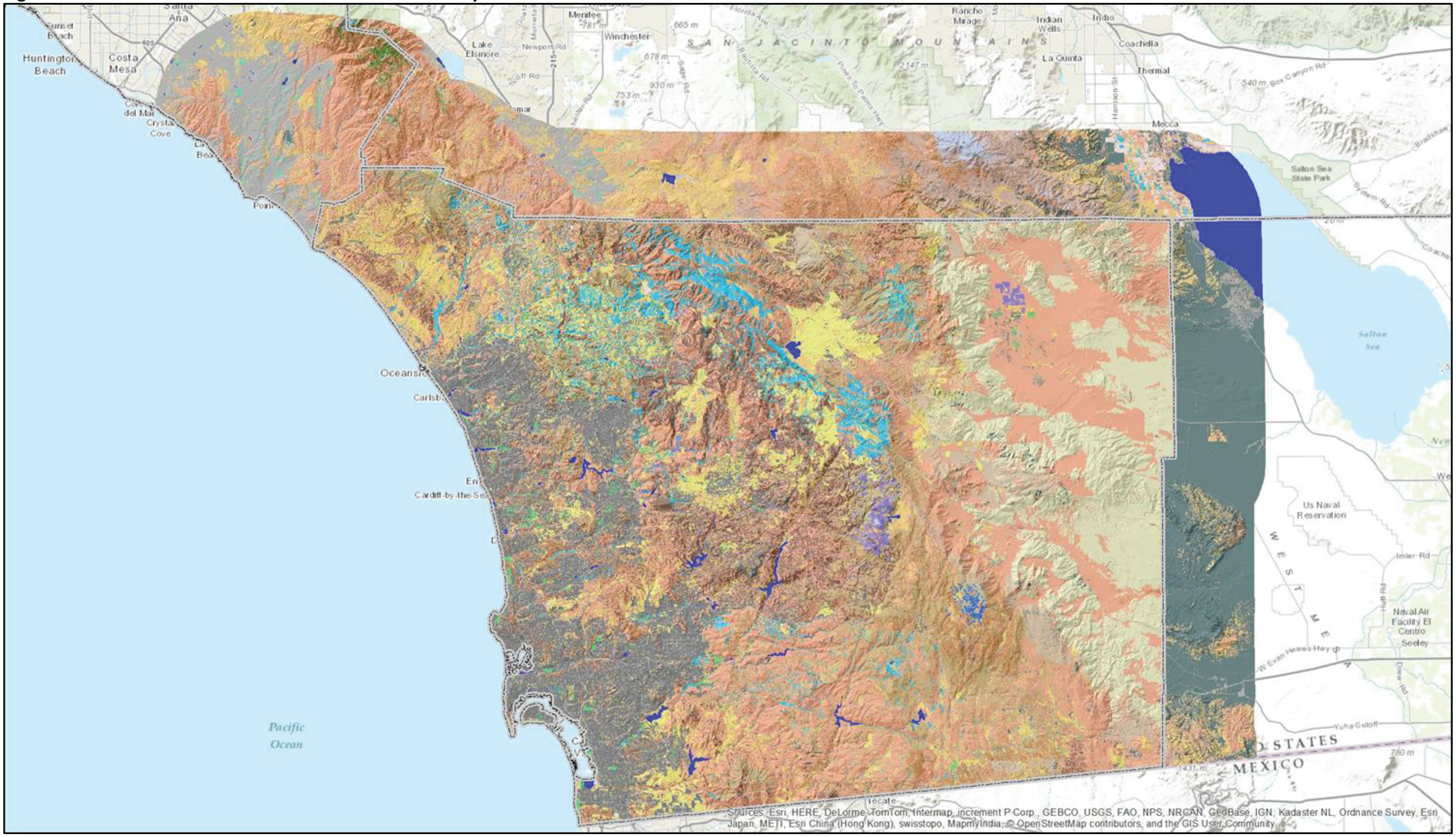
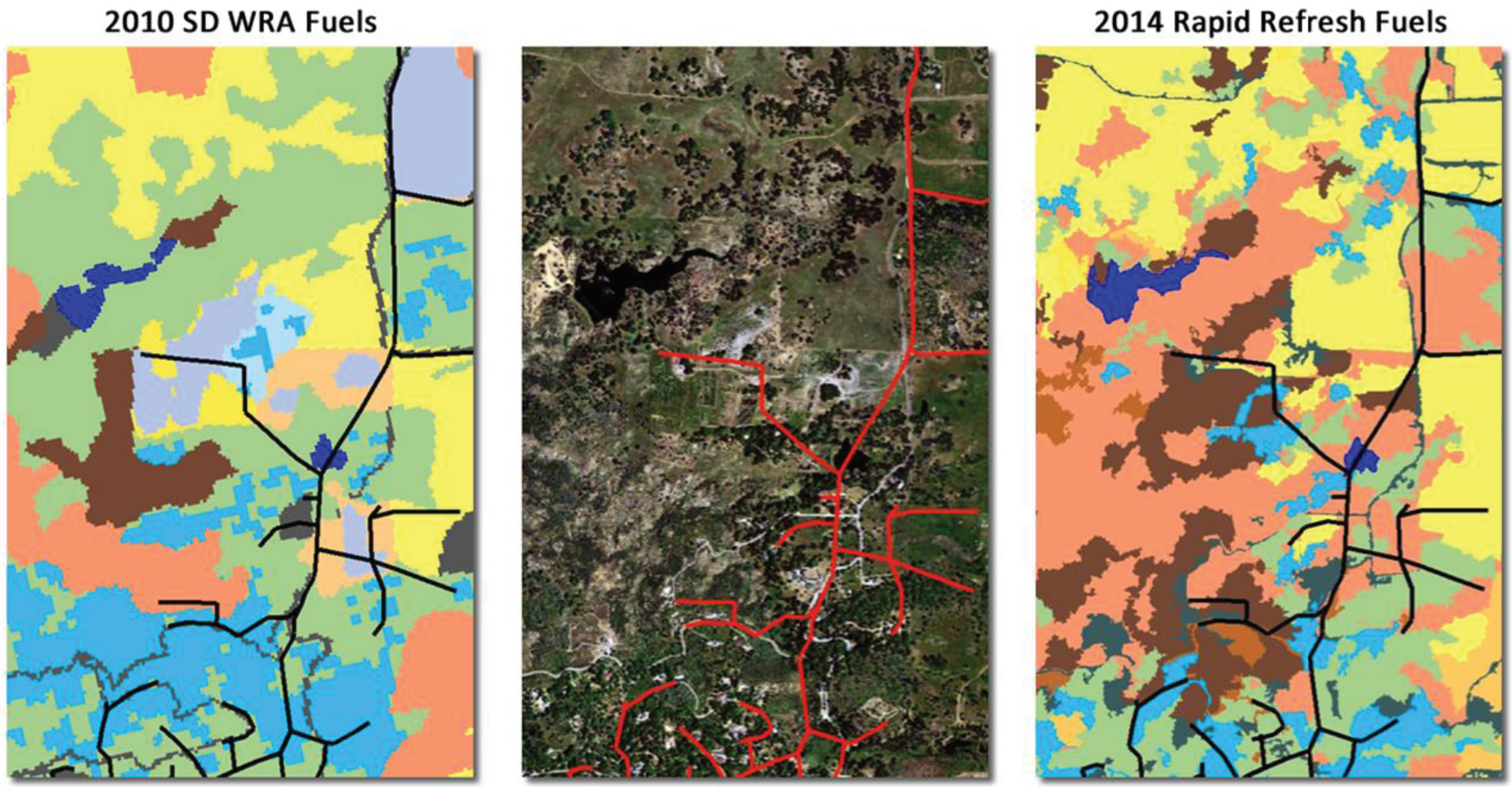
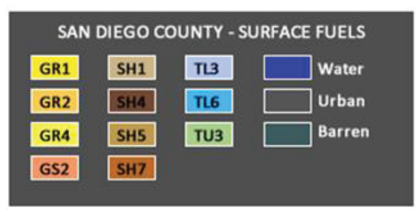


Figure 15. Comparison of 2010 fuels and 2014 fuels created by Technosylva for the WRRM project.



As part of the 2010 San Diego County Wildfire Risk Assessment project, fuels were derived by crosswalking the County Land Use & Planning vegetation dataset. This dataset is 10m resolution.



The 2010 fuels were enhanced using Landsat 8 imagery to reflect recent landscape disturbances, and a more accurate delineation near SDG&E assets.

Weather Data

Data that describes weather conditions most common when fires occur is a key input into the fire growth model. To compile appropriate weather data, an analysis of historical weather data was required. Several different data sources exist for compiling this data. Technosylva has undertaken an analysis of these sources and selected the SDG&E weather data as the richest data for deriving the weather conditions to be used in the WRRM. This section describes the data and requirements for this component.

The main purpose of this task was to analyze climatic variables to obtain weather synoptic situations, in order to get parameters for calculating wildfire behavior and, consequently, wildland fire risk.

There are several options that could be used to create the weather conditions for the simulation framework including:

- Weather station data from Mesowest
- Percentile weather for weather influence zones defined in the SD WRA project, and
- SDG&E historic Weather Research and Forecasting (WRF) data for Southern California.

Based on the characteristics of these data sources we have selected the SDG&E WRF data. This rich dataset, provided by SDG&E, includes 30 years of historical hourly data coming from the WRF model. Although it needs an innovative and complex process to make it useful for the fire modeling, it provides the best possible inputs for the simulations, and resulted in much more accurate risk analysis. The key variables used included:

- Wind vectors
- 1 h Dead Fuel Moisture Content
- 10 h Dead Fuel Moisture Content
- 100 h Dead Fuel Moisture Content
- Live Fuel Moisture

The raw data in the SDG&E NetCDF files cannot be used directly; they have to be processed to evaluate the distribution of the results and then categorized so we can define extreme, high, or average fire weather conditions to be used for the risk analysis and provide a metric of its probability of occurrence. To summarize all this data, percentile analysis was generated to describe a density function for any parameter of interest. These functions define the probability of each parameter occurrence to be used in a probabilistic wildfire behavior simulation model. The entire amount of hourly data for a pixel of 3x3 km was analyzed, and an accumulated frequencies curve was created. The following figure shows the results of this analysis for a specific parameter – 10h Dead Fuel Moisture Content.

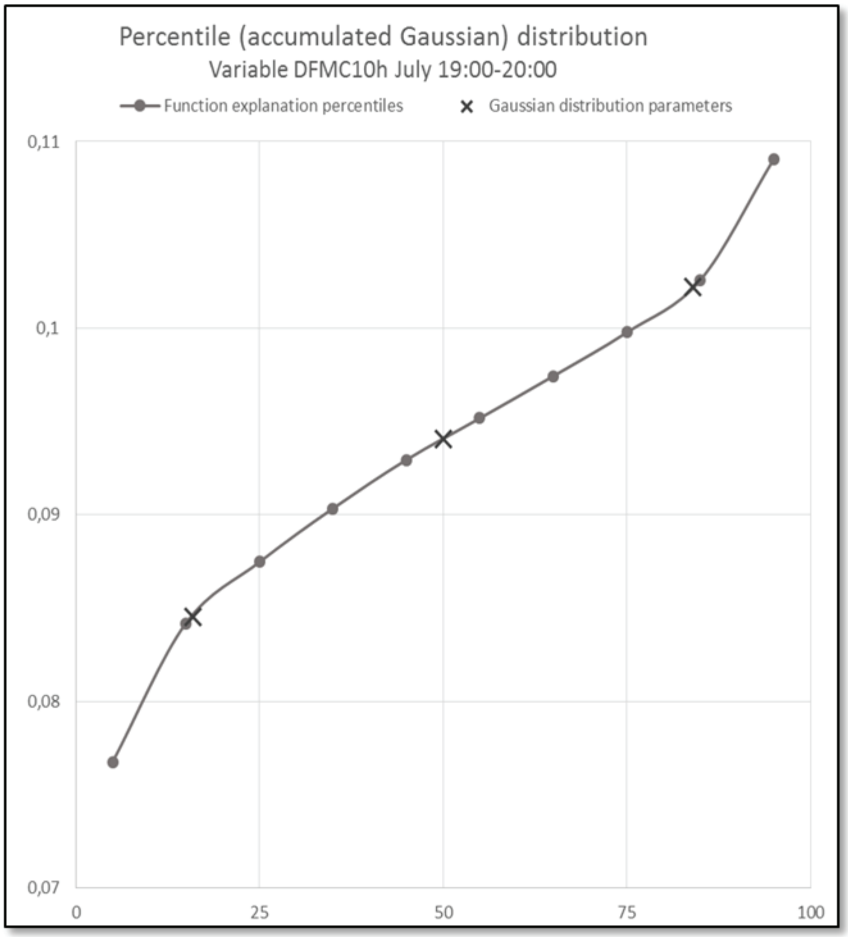


Figure 16. Cumulative (Gaussian) distribution of percentiles density function. Parameter: 10h Dead Fuel Moisture Content. Time dimension: July, 19:00 - 20:00 period. In this example, the mean value is 9.5%, and the more extreme conditions are when FM is minimum, the 5^th^ percentile value is 7.5%.

The final result of this analysis is a GIS database with a percentile distribution layer of every fire weather variable for every hour in a month for the last 30 years. This provides a rich dataset for simulating fires for any date and time in the WRRM fire growth component. The following figure presents an example GIS dataset for a specific variable, date and time. Note that numerous GIS datasets have been created reflecting various parameters for different times and conditions.

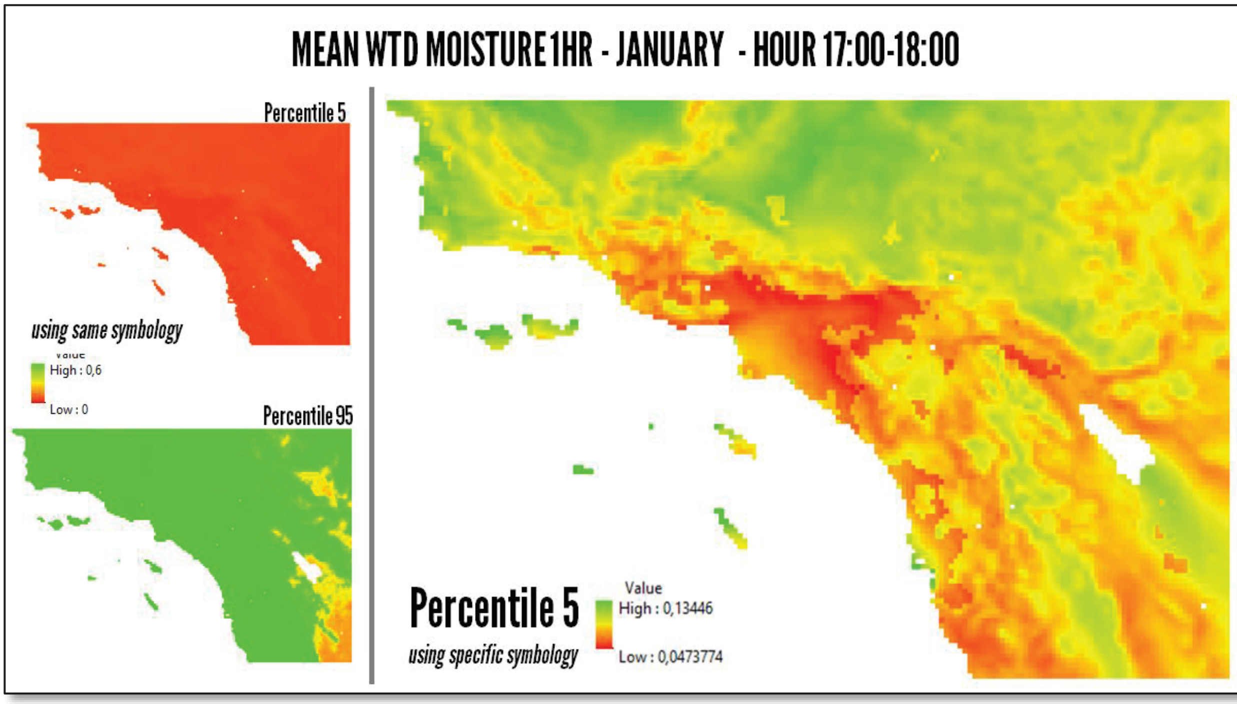
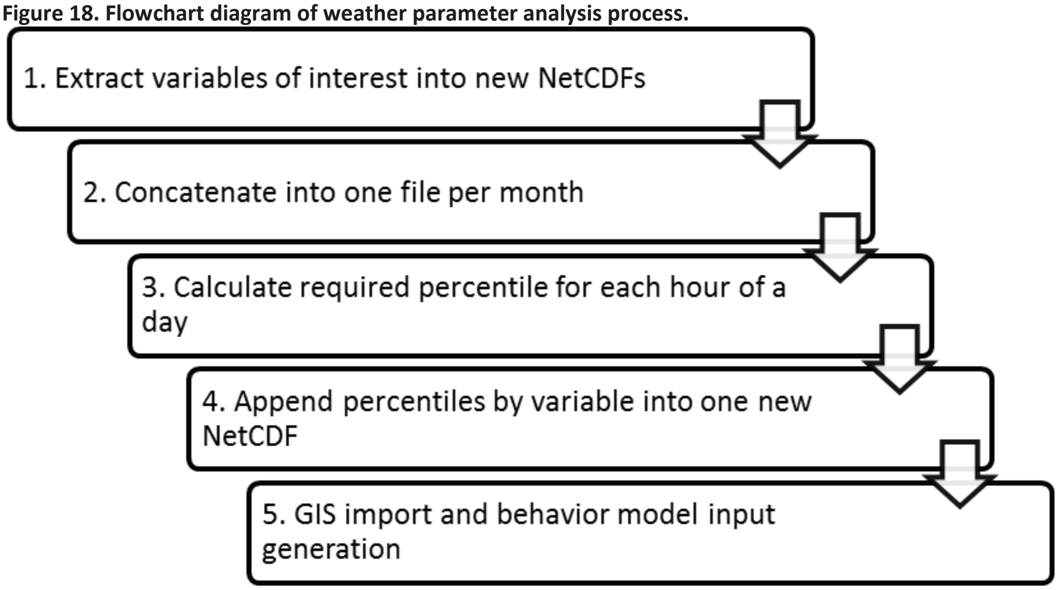


Figure 17. Example of fire weather variable GIS layer, ready to simulate for Southern California: 1hr fuel moisture for January from 6 to 7 pm. Percentile 5 shows lower values found, only 5% of the 30 years of data are below these values.

Weather Data Processing

A complex process was undertaken to complete the data analysis and create the necessary GIS datasets. The following figure presents the general steps in the process.

Figure 18. Flowchart diagram of weather parameter analysis process.



A detailed description of the processing methods identified in the figure above can be found in Appendix B. The following three figures present example GIS outputs derived for San Diego County for:

- Month and hour for a fixed percentile
- Percentile variation for a fixed time (month and hour), and
- Percentile and month for a fixed hour.

Figure 19. Monthly and hourly distribution of the 50th percentile for the variable 1 h fuel moisture.

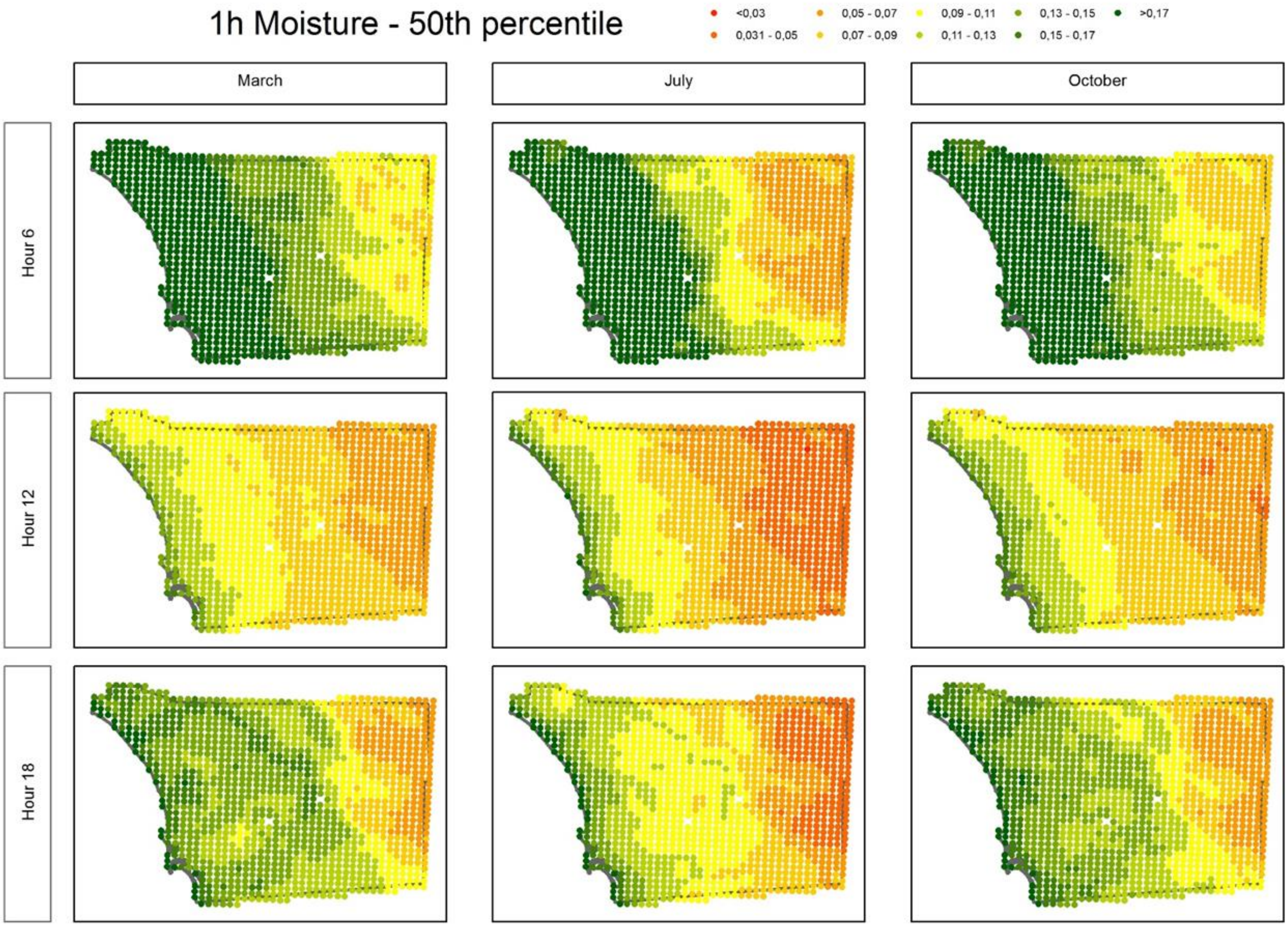


Figure 20. Percentile distribution of the variable 10 h fuel moisture for August, from 6 pm to 7 pm.

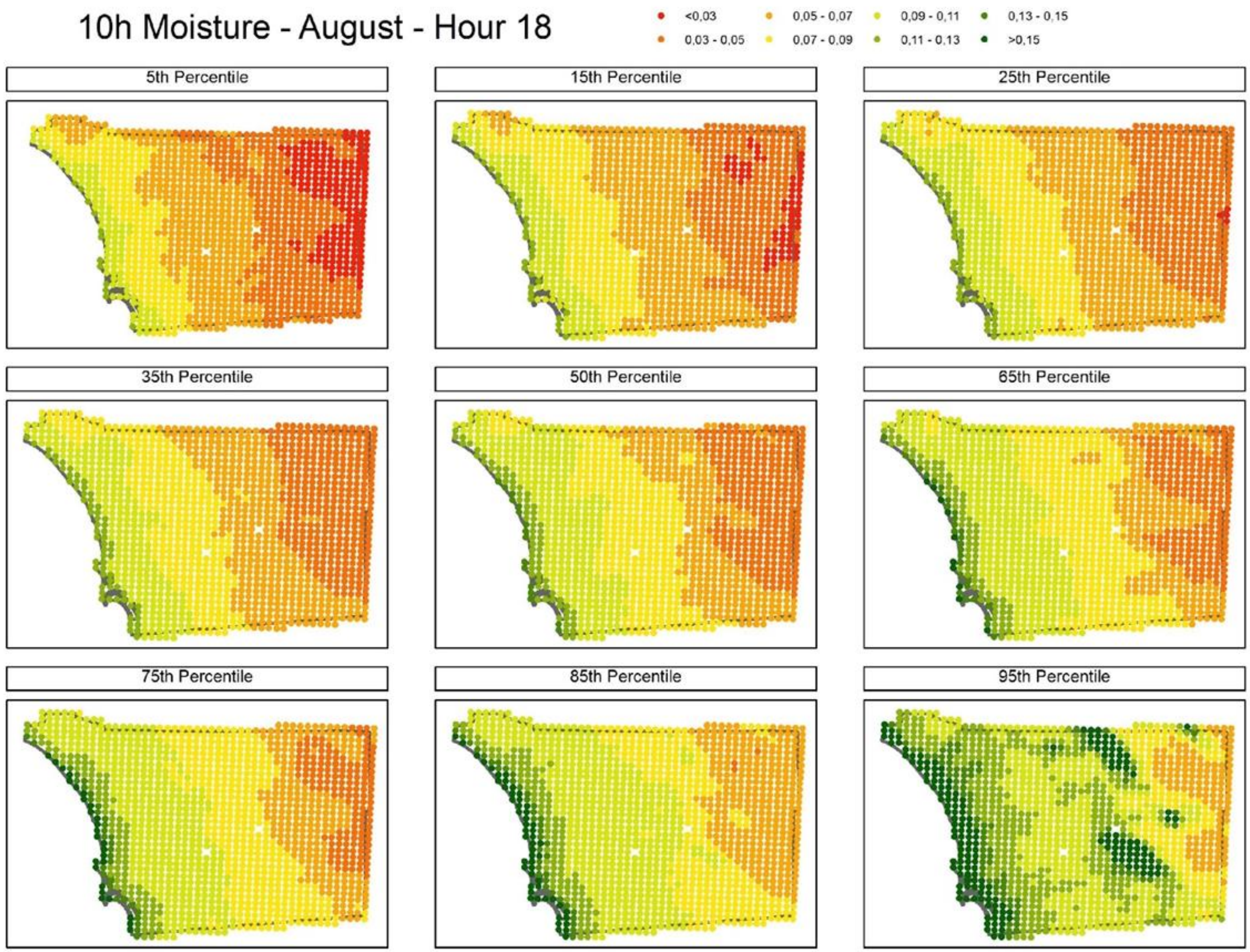
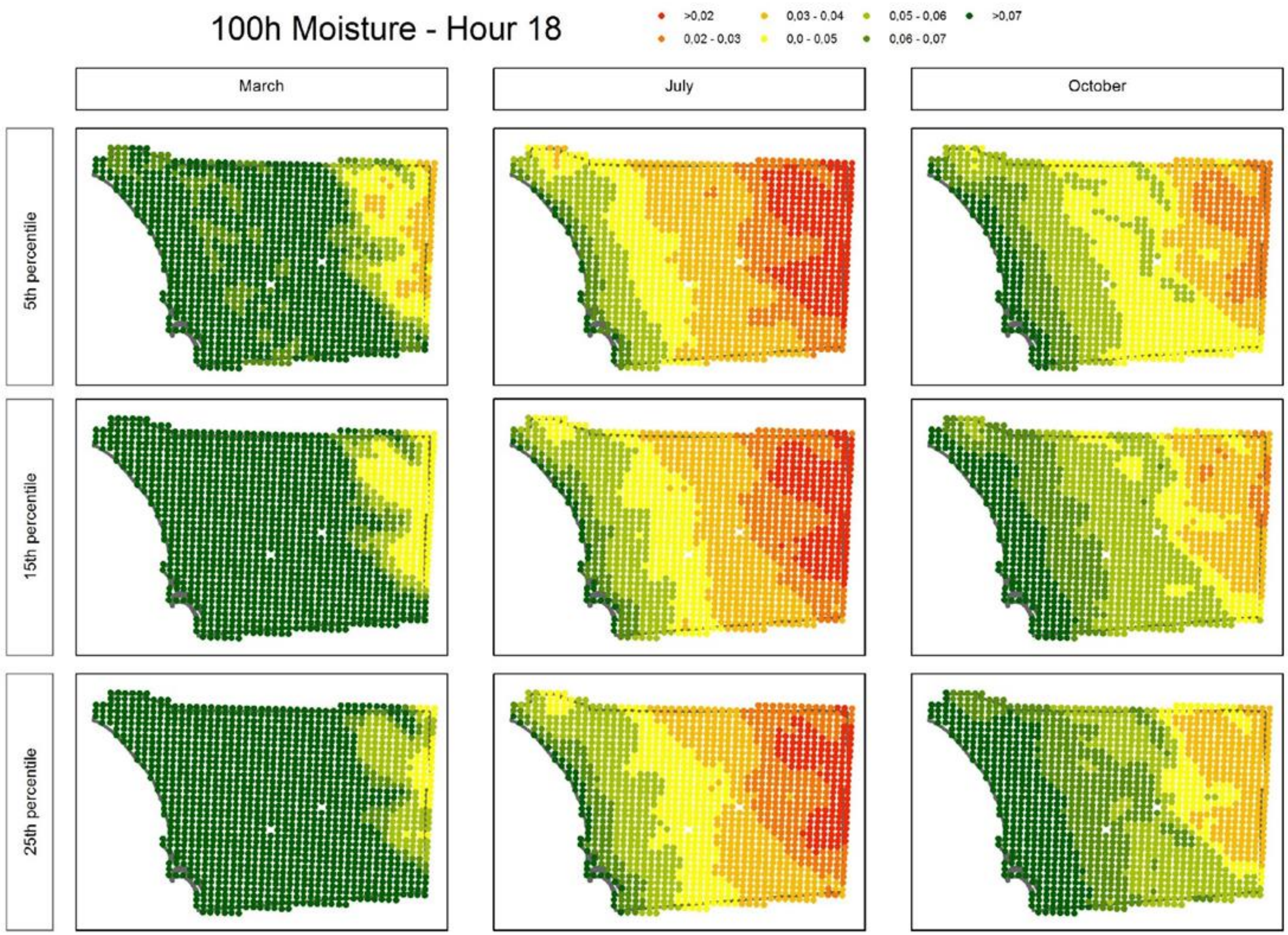


Figure 21. Monthly and percentile distribution of the variable 100 h fuel moisture from 6 pm to 7 pm.



Incident Parameters

Fire history can also be a good indicator of the time and weather conditions when wildfires can be expected to occur. The SDG&E database of fire history collected and maintained by the SDG&E Fire Coordinators was obtained and analyzed to determine characteristics of previous wildfires.[17] This information is helpful in identifying the typical conditions when fires occurred and can be used to tailor the weather data used in the WRRM fire growth simulations. The fire history data represents fires that occurred from 2006 to 2014. Using the SDG&E fire history dataset an analysis was undertaken to determine the temporal distribution of incidents and their duration.

The ability to utilize this historical data provides good insight into the weather conditions that are most common for fire ignitions. Accordingly, based on the results of this analysis, we were able to set the duration and starting time for defining the weather conditions for the fire growth model simulations. Specific weather parameters were defined during Phase 4 (Model Development) and verified with SDG&E staff.

Wildfire Spread Modeling and Stochastic Wildfire Simulations

Technosylva has developed a state of the art wildfire behavior simulation tool called Wildfire Analyst™ that was used to complete the fire growth modeling. Wildfire Analyst uses several well-known and validated fire spread models used in software like BEHAVE (Andrews 1986), FARSITE (Finney 1998), and NEXUS (Scott 1999). The surface fire spread model utilized is Rothermel's (1972) fire model together with the modifications proposed by Albini (1976). This model provides an estimation of the maximum Rate of Spread of the fire based on fuel characteristics, moisture content (1h, 10h, 100h, live and herbaceous), wind speed at midflame and the terrain slope. More explicitly, the spread model is based on the following simplified formula:

$$ROS= I_R \xi (1+\Phi w+ \Phi s) / \rho_b \varepsilon Q_{ig}$$

Here, I_R is the reaction intensity, ξ the propagating flux ratio, ρ_b the oven-dry bulk density, ε the effective heating number (the proportion of fuel that is heated before ignition occurs), Q_{ig} the heat of pre-ignition, and $(1+\Phi w+ \Phi s)$ is a multiplication factor accounting for slope and wind speed and given by:

$$\Phi s =5.275\ \beta^{-0.3} \tan \varphi^2 \quad \text{and} \quad \Phi w= C(3.281U)^B (\beta/ \beta_{op})^{-E}$$

where β is the packing ratio for the fuel bed and φ the slope, U is the midflame wind speed (m/s) and the functions C, B and E are dependent on the fuel particle sizes of the fuel bed. The rate of energy release per unit of length of the fire front is given by Byram's fireline intensity (Byram 1959) and is given by:

$$I_b= I_R\ 12.6\ ROS / (60\sigma)$$

where σ is the characteristic surface area to volume ratio of the fuel bed, I_R is the reaction intensity, and ROS the rate of spread.

Rothermel's model estimates the Rate of Spread of the fire but only on the direction of maximum spread. In order to obtain an expression of the rate of spread for different directions an elliptical form of the fire should be assumed (Anderson and others 1983). The elliptical shape has the ignition source in one of its foci and its eccentricity depends on fuel characteristics, wind and surface slope. The present implementation for the eccentricity follows FARSITE (Finney 1988), which uses a virtual wind speed obtained from the factors Φw and Φs that produces the combined effect of slope and wind on the fire spread rate. Once this virtual wind is known, the length to breath ratio is given by:

$$LB= 0.936*\exp(0.1147\ U_{virtual}) + 0.461\exp(-0.0692U_{virtual}) - 0.397;$$

[17] Note that many of the fire records did not have a lat/long to identify the explicit location of the fire. In this situation, geo-coding based on the fire street address listed was used to define the fire location.

Under certain circumstances surface fire may affect the overstory turning into a crown fire. The initiation model used is based on (Van Wagner 1977; Scott and Reinhardt 2001). The main initiation criterion is based on the critical fireline intensity of the surface fire given by:

$$I = (CBH(460+25.9FMC)/100)^{3/2}$$

where CBH is the canopy base height and FMC is the canopy fuel moisture content. The ROS of the associated active crown fire is given by $3.34(R_{10})_{40\%}$ where $(R_{10})_{40\%}$ is the spread rate predicted with Rothermel's (1972) surface fire model using the fuel characteristics for FM 10 and midflame wind speed set at 40 percent of the 6.1-m wind speed (Rothermel 1991).

Finally, the two dimensional evolution of the fire is computed as a discrete process of ignitions across a regularly spaced landscape grid through a 'minimum arrival time' function (Finney 2002). Wildfire Analyst produces a suite of outputs that describe fire behavior and spread. These include:

- Static and dynamic Rate of Spread (ROS), flame length and fire intensity
- Minimum Travel Time fire paths (Finney 2006)
- Time of Arrival (i.e. fire perimeters) (Finney 2006)
- Crown fire (Van Wagner 1977; Rothermel 1991)
- High Definition Wind field computed by WINDNINJA (Forhofer 2007)
- Static and dynamic out of suppression control analysis, and
- Campbell Prediction System (Campbell 2005) alignment of forces

With the updated fuels, the weather database and the temporal distribution of incidents, a fire growth model provides the best possible estimation of fire growth for asset ignitions. A stochastic approach was utilized with a large sample of possible weather scenarios and to determine the variability in fire growth from each asset to create an overall asset wildfire probability dataset.

The result of this approach is not a single progression, but numerous spread simulations (fireplains) for each possible asset ignition location. Impacts are calculated for each simulation using the HVRA vulnerability input data (structure values). These impacts are then summed using a weighted distribution to determine the Conditional Impacts associated with that specific asset. More detail on this process is provided in the following sections.

Creating the Fire Growth Simulation Outputs for the WRRM

As described in the previous section, the WRRM used state-of-the-art stochastic wildfire simulations to quantify fire growth potential for each SDG&E asset. The simulations are conducted in a way that permits integration with the next WRRM component—HVRA vulnerability. The vulnerability model is what ultimately defines the impacts of potential fires and provides the foundation for calculating risk reduction and evaluating different hardening projects.

For the fire growth potential component of the WRRM, Technosylva ran the stochastic wildfire simulations on its own super computers and compiled the results into a spatial database of Conditional Impacts for each possible ignition location (asset). This is referred to as the fire growth database. It is not necessary to build real-time fire modeling capability into the WRRM software itself. The fire growth potential simulations are extremely time-consuming and CPU intensive, so this design greatly improves the operational performance of the WRRM software as it will be used by SDG&E personnel for evaluating risk reduction projects.[18]

[18] This approach of modeling all possible asset ignitions and fire growth outputs is not only time consuming, but also relatively static in nature, as fuels are slow to change over time, and weather conditions are well defined from our analysis. Accordingly, real-time modeling is not required. This approach also greatly reduces the cost of WRRM model development as licensing of Technosylva's Wildfire Analyst. Software is not necessary for the WRRM to operate. It is only required to create the fire growth database.

Due to the large number of assets in the electric power distribution system, it may not be possible to simulate fire growth potential for each and every asset location. Nor is it necessary to do so, for two reasons. First, many of the assets are co-located, or are so close together that they are effectively in the same location. For example, a three-phase electric power distribution conductor span has three separate assets at the same location. Moreover, as Technosylva has learned in previous projects, fire growth potential is relatively insensitive to small changes in ignition location. The reason for this relative insensitivity is that the spatial domain of the fire environment around the ignition location—the fireplain—is quite large, so a small shift does not change the fire environment significantly. For use in the WRRM, Technosylva conducted an analysis to determine the optimum resolution of the fire growth asset ignitions, leveraging the analysis and definition of asset classes.

For the SDG&E service territory 38,569 possible asset ignition locations were identified. For each asset location the following unique conditions were modeled:

- 5 wind speeds
- 8 wind directions
- 3 fuel moisture scenarios
- 15 hourly durations

Overall, 69,424,200 fire simulations were conducted for the fire growth model. Impacts results were determined and stored for each simulation in the fire growth database. This raw information was used in the vulnerability model to calculate Conditional Impacts.

Simulation Examples
To further demonstrate the processing logic of the fire growth model component, Figure 22 presents an example of multiple fire growth simulations from a specific SDG&E asset. These examples all use the same exact asset ignition location, however, vary in weather conditions used. Three 15 hour simulations are presented. The weather scenarios used are determined by using the gridded historical data provided by SDG&E. The asset ignition location is shown by the ⊗ symbol. The size and shape of the probabilistic fireplains depends on the fuel, topography and weather (primarily wind speed and direction) surrounding the asset.

3. Vulnerability and Impacts

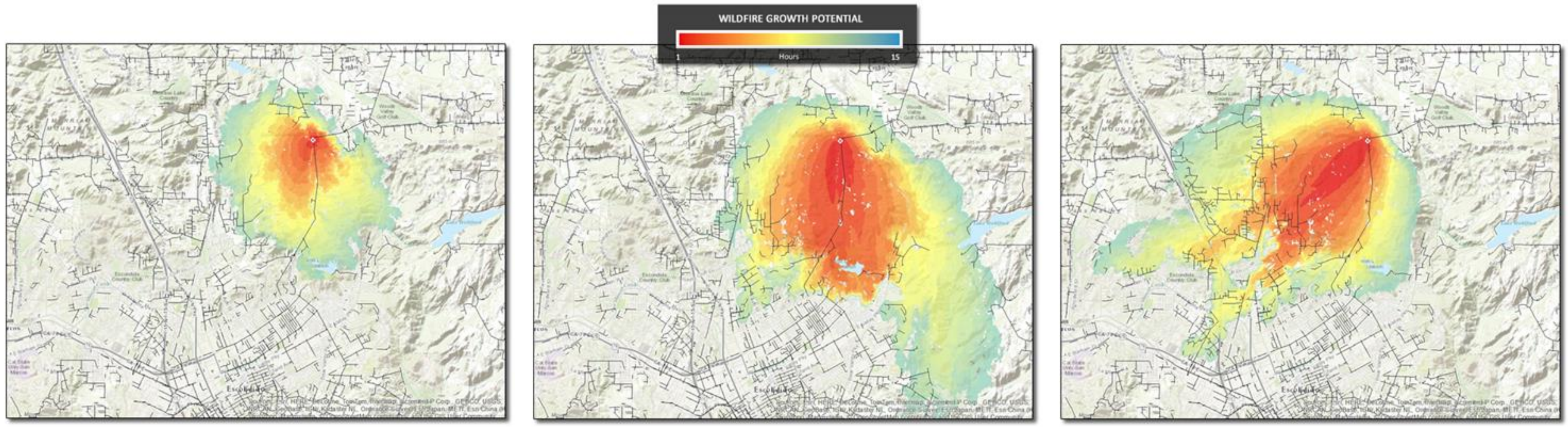
Just as fuel, weather and topography vary across the service territory, so, too, does the vulnerability and value of highly valued resources and assets that can be damaged by wildfire. Even if fire growth potential were uniform, wildfire risk would vary across the territory depending on the value and spatial distribution of homes, structures and other highly values resources.

The asset vulnerability and value component of the WRRM is based on datasets related to the location and susceptibility to wildfire of highly valued resources and assets (HVRAs) across the service territory. Exposure is the location of the HVRA with respect to wildfire hazard, while susceptibility refers to the level of impact (leading to loss) caused by wildfire of different intensities. For example, not all homes within a fire perimeter suffer the same level of impact. The level of impact will be a function of the fire intensity to which it was exposed and the condition of the home (or other resource value). Several different factors were considered for the WRRM implementation, however, SDG&E ultimately decided upon using the value of structures as the primary HVRA and measure of impact.

Vulnerability Input Data
Based on previous experience working in San Diego County assessing wildfire values-at-risk, Technosylva selected the County Land Use and Planning Assessor parcel database as the best available source for identifying structure location and value. This dataset is readily available as updates occur by the county assessor department and also provides the attributes necessary to calculate a structure value for on each parcel.

GIS data that identifies the specific location of structures across the service territory is not readily available. Accordingly, the County Assessor parcel data represents the best source for determining a value related to structure vulnerability. In reviewing the Assessor attributes it was decided that Total Assessor Dollar Value was not a good indicator of true value of the structures. In addition, the total number of structures on a parcel is not easily defined.

Figure 22. Example wildfire growth simulations for a single asset location.



Example wildfire growth simulations for 15 hour duration from a single asset ignition location

An analysis was conducted that resulted in the following criteria used to define the structure vulnerability input dataset:

1. For each parcel, a total value of structures on that parcel was calculated as total square footage of the structures x 300, where 300 represents a standard dollar value per square foot required to rebuild that structure for residential land use zones. For parcels in commercial and industrial land use zones, a value of 350 was used. Parcels that did not have structures were excluded.
2. The total value was then spread out evenly across the area of the parcel to create a fine grid of value per grid cell. This was undertaken since the specific location of the structure(s) on the parcel is spatially unknown. Accordingly, the value was spread out evenly across the parcel. A fine cell resolution was selected to accommodate small parcels.
3. Since wildfires do not typically destroy all structures impacted during an incident, the total value of the structures on the parcel were multiplied by a percent loss factor to reflect a more accurate representation of potential losses.

Percent loss for a structure can vary due to several factors, including structure age and building materials, containment capability of the local fire department during wildfires, and landscape conditions, such as surrounding fuels, defensible space, and prevalent wind conditions (i.e. wind corridors). The SDG&E data provided for percent loss used polygons classified in three (3) tiers – 20% loss, 15% loss, and 5% loss. The % loss factor was then multiplied by the value per cell to create an adjusted value per cell.

Note that for some of the SDG&E service territory a slightly modified approach was used due to the lack of required County Assessor data for Orange and Riverside counties. A detailed description of the data processing methods is presented in Appendix C.

For each simulation, as a wildfire progresses across the landscape it will consume structure value cells as it moves across a parcel. The total value of all cells consumed is summed for each simulation perimeter so that the impacts for every hour of the fire simulation are known and stored. The impacts will be the total structure value consumed for each hour. These impacts are calculated and stored for every simulation conducted and provide the database for calculating Conditional Impacts. However, the calculation of Conditional Impacts does not simply use the sum of structure impacts. Instead, a weighting utility is applied for each hour of each simulation for a specific asset ignition location. This allows for consideration of other factors such as most prevalent weather conditions, etc.

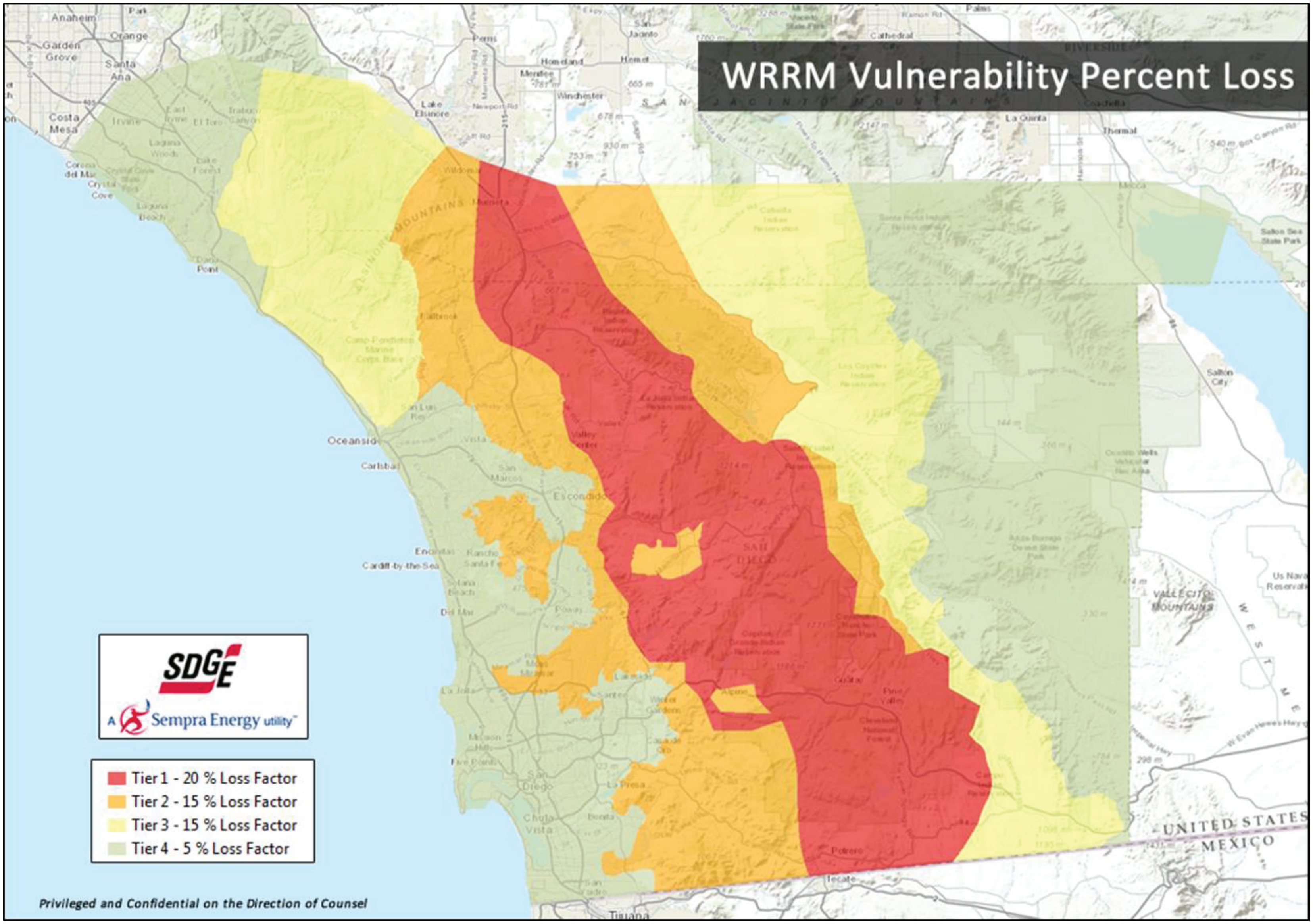


Figure 23. WRRM vulnerability percent loss areas.

Key Vulnerability Analysis Components

The vulnerability submodel contains several key elements that are critical for calculating wildfire impacts that incorporate observed and expected fire and weather conditions. These include:

- Percent loss of structures exposed to wildfires for different geographic areas (structure susceptibility)
- Encroachment of wildfires into urban areas (pyrosmosis)
- Weather distributions for fire growth simulations
- Duration of wildfires for different weather scenarios
- Correlation of equipment failure for specific asset types for wind speeds (wind factor)
- Typical suppression capabilities of local firefighting agencies (containment success)

Analysis was undertaken by the WRRM technical team to investigate these elements. A summary is provided below.

Percent Loss of Structures

It is well understood that not all structures are created equal and accordingly vary in their susceptibility to fire. Since the Fire Growth Model and Vulnerability model sum the potential loss in structure value it is important that this process include a realistic method for calculating the percent loss of structures. The methods described in the section above document the approach implemented in the WRRM that utilized a range of loss rates varying from 5% to 20% across the SDG&E service territory. Expert opinion was used to develop a map of geographic areas where loss rates are understood to vary. This was used to adjust the Conditional Impacts to provide a more accurate portrayal of potential losses.

Encroachment

Wildfires often encroach into urban areas burning homes where minimal vegetation fuels exist. The distance of encroachment varies depending on the fire intensity, wind conditions, terrain characteristics, and defensible space around the structures. For the WRRM Fire Growth Model several different encroachment distances were tested and a 100 meter maximum distance was used depending on the level of spread and fire intensity of the fire when it reached the urban area. This ensured that structures on the edge of wildland areas would be impacted by wildfires, but a reasonable level of penetration into the urban area occurred.

Weather Distributions

Conditional Impacts are summed based on the distribution of weather conditions from which they were calculated. This allows the WRRM to weight impacts based on most common weather situations. For the WRRM weather distributions were only used for the months June to October, and for observations recorded at 14:00, 15:00 and 16:00. This reflects when the vast majority of fires occur in the territory.

Wildfire Duration

Wildfire durations vary with weather conditions. For the WRRM Fire Growth Model, a 15 hour duration was used for all simulations. However, not all impacts for each hour are weighted equally in the compilation of impact totals for a simulation. Accordingly, four distributions of duration were defined by the technical team and assigned to the 120 different weather scenarios used. This allowed the WRRM to utilize longer mean durations for weather scenarios that included higher wind speeds and drier fuels (fuel moisture).

Wind Speeds and Equipment Failure Rates

Since it is well understood that specific asset types, such as conductors and poles, have greater equipment failure likelihood during high wind scenarios, the model was calibrated to include a wind factor weighting. The wind factor is used to adjust failure rate for different asset types in certain weather scenarios.

Containment Success

In some areas of the service territory many equipment related wildfires are successfully contained to a very small size minimizing impacts from those fires. The containment rates vary across the territory as a function of the local fire department capabilities and distance to a fire station. Analysis was undertaken to investigate response time from a fire station and test the likelihood of successful containment prior to any impact occurring. Based on the results it was agreed that this component required more detailed investigation before it should be integrated into the WRRM model. As such, the factor is not included in the initial version of the WRRM.

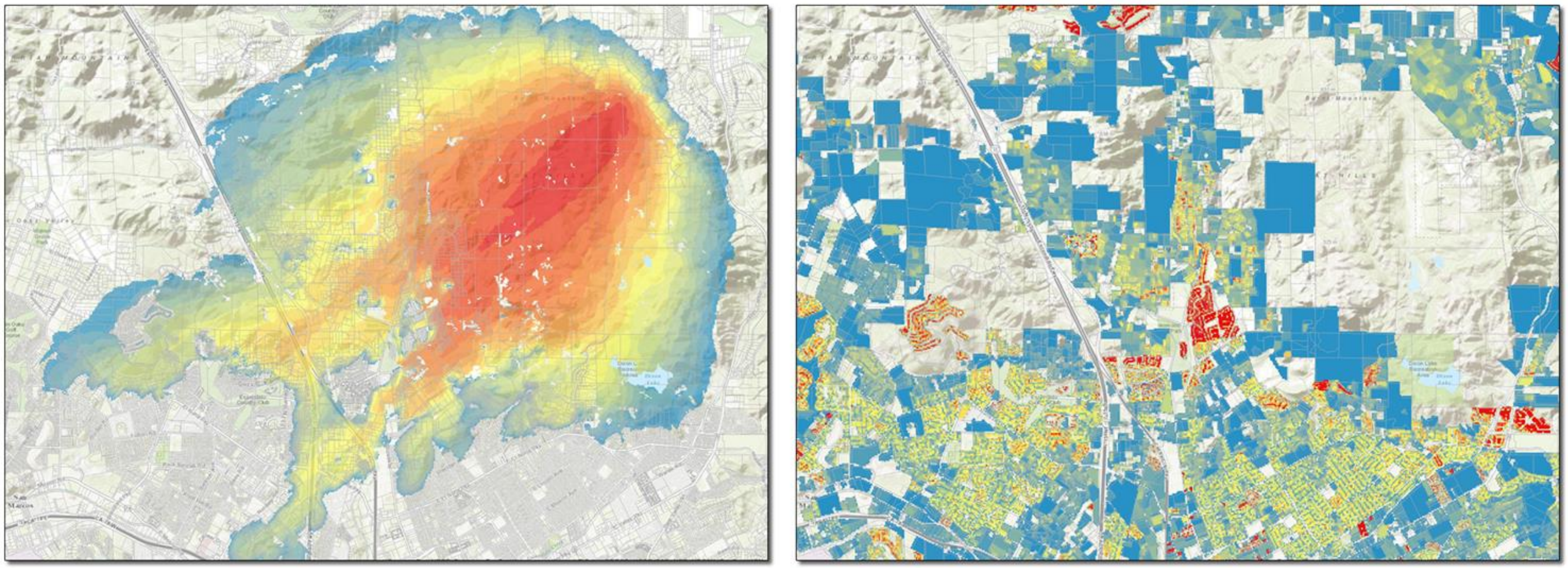
4. Risk Reduction Model

The risk reduction component of the WRRM integrates information from the first three model components. In the WRRM, conditional exposure is measured in Structure Value to facilitate use with hardening projects. The interpretation of conditional exposure at a given location is "a wildfire caused by an asset failure at this location would tend to result in costs and losses." Here, "tend to result in" is determined by calculating the average exposure of many hundreds of simulated wildfires occurring in weather conditions associated with asset failures.

The conditional exposure output value is called Conditional Impacts. This combination is accomplished with an expected value calculation that estimates the average exposure to costs and losses of an equipment-related wildfire occurring at the point. In Figure 24 (right panel) we show a representation of potential losses associated with wildfire damage to structures. County assessor parcels are shown in each map as grey lines. The assessor data is the source for calculating the structure loss values.

The left map shows a single simulation representing the spread of a wildfire for 15 hours given specific weather and fuel moisture conditions. By overlaying the simulation with the structure value the total impacts can be calculated on a per hour basis. By summing all the simulations extents for a specific asset a Burn Probability can be determined for that asset.

Figure 24. The WRRM Vulnerability model combines the multiple fire simulations produced by the fire growth model (left) with the vulnerability component (right) to calculate Conditional Impacts.



Wildfire simulation for a 15 hour duration represents the fireplain for the specific asset ignition.

Structure values adjusted by percent loss associated with the fireplain for the specific asset ignition.

The calculation is simply the sum-product of *BP* and *C+L* for all pixels (*j*) in the fireplain.

$$conditional\ exposure = \sum_{j} BP_j * (C + L)_j$$

Conditional exposure represents the average costs and losses associated with a wildfire starting at the location. For the example shown in Figure 24, the conditional exposure at the location is $25 million. The *C+L* for some of the simulated fires was less, and for others it was more, but the mean was $25 million.

Conditional Impacts is the key data input into the Risk Reduction Model. Figure 25 identifies the key outputs of the model, expected impacts and risk reduction. The combination of Conditional Impacts with individual asset failure rate and ignition rate is used to calculate expected impacts.

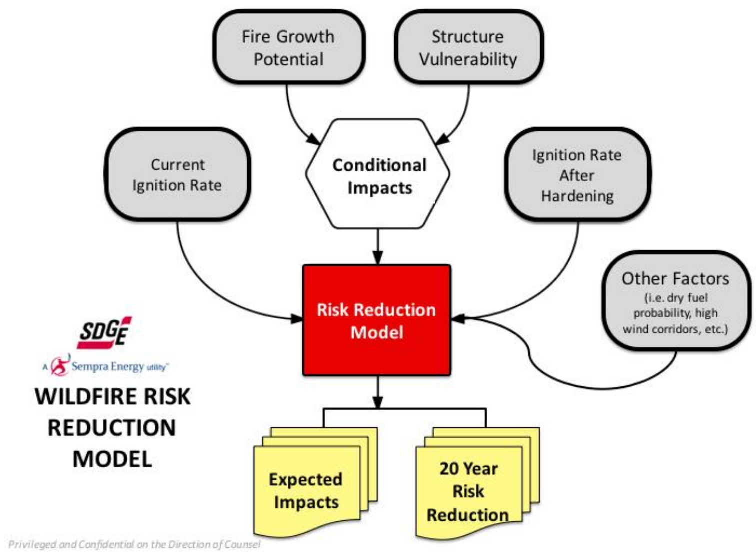


Figure 25. The Risk Reduction Model integrates the Conditional Impacts with ignition rate information for assets to calculate the Expected Impacts.

A risk reduction project is the replacement of certain system assets with newer assets that have, presumably, a lower likelihood of failure and subsequent wildfire ignition. The risk reduction model calculates the risk reduction value for each asset. This risk reduction is based on subtracting the Expected Impacts for the new replacement asset from the current asset Expected Impacts to determine the change in expected impact.

The risk reduction benefit gained by a hardening project is experienced not only in the first year after mitigation, but for a number of years following the project. The WRRM design accommodates any planning horizon desired by SDG&E, although the technical team agreed upon a 20-year horizon for the initial implementation of the WRRM. Example calculations are based on a 20-year planning horizon, meaning that the risk reduction benefit of a hardening project is experienced for 20 years into the future.

The risk reduction model produces several results an individual asset in a project, including:

- Replacement asset expected impact
- 20-yr risk reduction
- Implied minimum ignition likelihood reduction (%)

The results of the Risk Reduction Model component are illustrated by continuing the example started above (a conductor span with an annual probability of igniting a fire of 0.0000695, or 69.5 fires per million spans per year). Let's further assume that the span is replaced with a new conductor that has a lower probability of igniting a fire—

40 fires per million spans per year (an annual probability 0.000040). At the asset location, recall from above that the mean exposure to wildfire costs and losses is $25 million if a fire should occur there.

The current annual wildfire risk at this location is the product of the probability of a fire start and the mean impact if one should occur.

$$Annual\ C + L = 0.0000695 * \$25M = \$1{,}738$$

Assuming for now that the discount rate equals the inflation rate, this expected annual *C+L* accumulates to $34,750 over the 20-year planning horizon. This is plotted as a solid black dot in Figure 30. For the reduced probability of ignition (0.0000400), this 20-yr total expected *C+L* falls to $20,000 (black square in Figure 30), a reduction of $14,750.

Assuming a hardening project cost of $5,000, the present net value of the project is $9,750, its benefit/cost ratio is almost 2.95, and the internal rate of return is 13.6%. The Risk Reduction Model component also calculates the implied minimum reduction in ignition likelihood required to offset the project cost. In this example, reducing the ignition likelihood from 69.5 fires per million assets per year to 59.5 would just offset the $5000 project cost. This implied minimum is shown as a light-colored diamond in Figure 26.

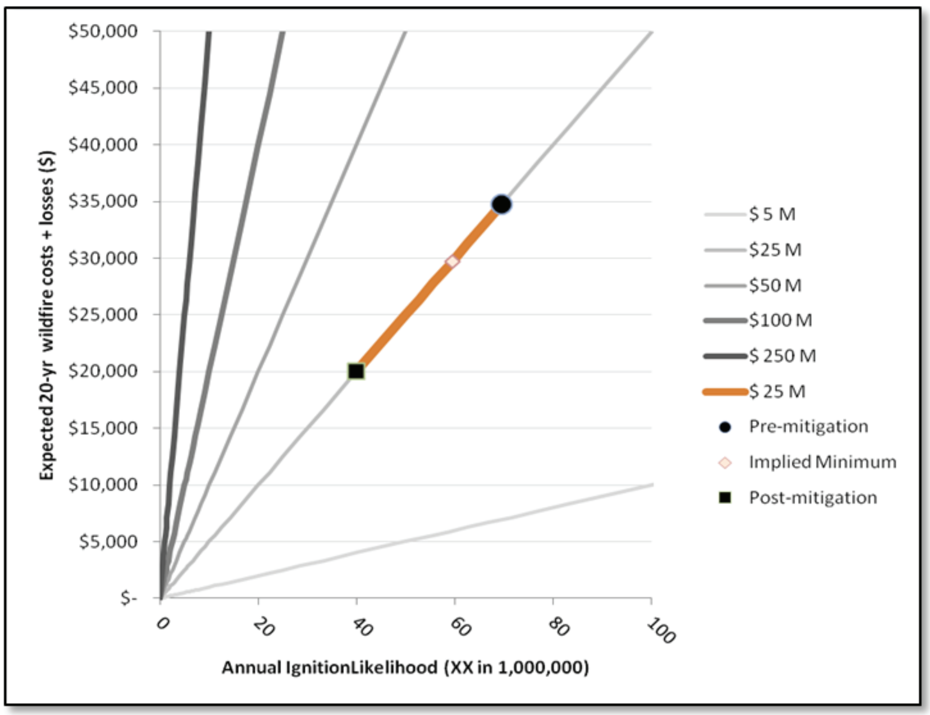


Figure 26. Graphical illustration of the Risk Reduction Model component calculations and relationships for a single electric power distribution asset.

The ignition likelihood on the X-axis refers to both the current and post-project IgnitionLikelihoods (referred to as the Replacement Asset). The Y-axis is the cumulative 20-year exposure to wildfire costs and losses. The reference lines indicate different levels of mean exposure at the asset location. The orange line indicates the effect of the hardening project at moving from the current to the post-mitigation IgnitionLikelihood. The "implied minimum" represents how much reduction in IgnitionLikelihood is required to break even, given the cost of the project.

Implementing the Risk Reduction Calculations

In an effort to provide a dynamic capability for SDG&E to evaluate risk reduction within the WRRM software using the model outputs, a technical approach was utilized that identified the most likely replacement assets to be used in a typical hardening project. By simply providing a data lookup table that identifies the typical replacement asset for all current Asset Classes, the WRRM software can calculate the Expected Impacts for the replacement asset (referred to as Replacement Expected Impact), as well as the Risk Reduction value. Please refer to Appendix A as an example of this data lookup table.

For example, a conductor that is #6 Cu Strand, with a span length greater than 300 feet, with splices, older than 30 years, is commonly replaced with a #2 AL conductor. This replacement is well understood and can be defined in advance. Since the equipment failure rate, and ignition rate, is known for all Asset Classes, the WRRM can calculate the Replacement Asset Expected Impacts, and hence the Risk Reduction value. The list of all possible asset subtypes and their relative equipment failure rates is predefined and stored in a database lookup table. This provides a consistent dataset for SDG&E to use for all project planning.

When a user selects specific assets to include in a hardening project using the WRRM software, a default set of replacement assets is already defined, so the Risk Reduction is calculated on-the-fly. A user is able to change the replacement asset if desired, inherently changing the asset ignition rate, resulting in a different Replacement Expected Impact and Risk Reduction output. This allows SDG&E engineers to immediately determine the level of risk reduction for a project and incorporate that information into their design and planning of hardening projects.

The WRRM calculates Expected Impacts and Risk Reduction on an individual asset basis. It also summarizes the metrics by Asset Classes, and also for the entire project. The user is able to generate an XLS report that lists the risk reduction values at all three scales.

D. WRRM Model Outputs

The WRRM model creates three key outputs associated with each SDG&E asset:

- Conditional Impact,
- Expected Impact, and
- Risk Reduction

Conditional Impacts are the mean wildfire impact given that an equipment-related wildfire occurs at a specific location. This can also be referred to as conditional risk.[19] Conditional impact is combined with ignition rate and wind factor characteristics to calculate the Expected Impact. It is calculated for each asset and can be summed to quantify the conditional impacts for a specific hardening project.

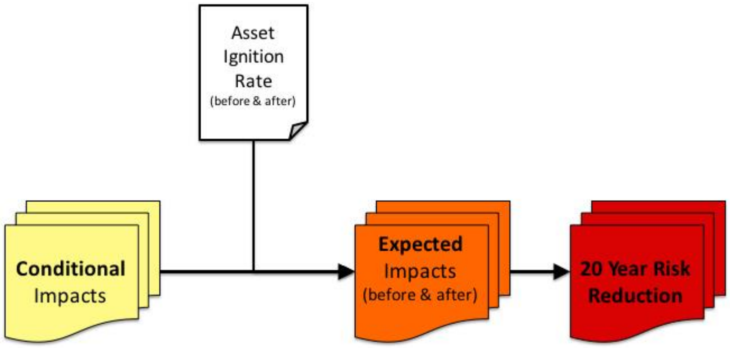
Expected Impacts are the mean annual equipment-related wildfire impact after incorporating the likelihood of equipment failure and subsequent wildfire (also referred to as expected risk). This is a primary output of the WRRM model. It is calculated for each asset and can be summed to quantify the expected impacts for a specific hardening project.

Risk Reduction is the expected risk over a 20 year planning horizon for an asset. This is the primary WRRM model output used to quantify risk reduction for an asset replacement. Risk reduction values are summed for assets in a specific hardening project to provide an overall risk reduction for that project.

The following figure shows the relationship between the risk outputs.

[19] The term "risk" is defined as the possible loss or harm occurring from a wildfire. For the WRRM project we use the term risk to refer to the overall model, not a specific output measure of loss. The term "impacts" is preferred.

Figure 27. Relationship between WRRM model outputs.



Note that the Expected Impact is calculated for both the current asset (situation) and the replacement asset to derive the Risk Reduction value. Equipment failure rate and ignition rate are reduced by new replacement assets and this provides the basis for calculating change to the Expected Impact (i.e. before and after replacement). The following figure presents an example of the current and replacement values calculated for a few individual conductor assets, from a sample hardening project report generated by the WRRM software.

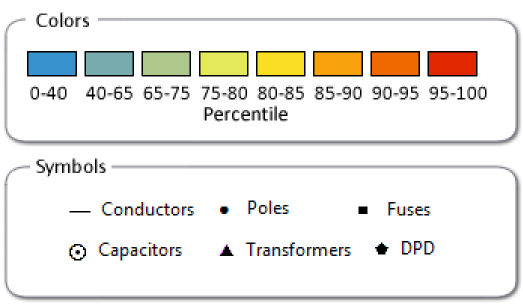
Figure 28. Example WRRM output fields for individual assets.

Baseline Risk								Replacement Risk			
Asset Class	Asset Type	Asset Age	Asset Subtype	Current Relative Failure Rate	Conditional Impact	Expected Annual Impact	Current Ignition Rate	Replacement Asset	Replacement Relative Failure Rate	Replacement Expected Impact	20 Year Risk Reduction
602130	CONDUCTOR	Unknown age	#4 Cu strand	0.178	446,453	34	0.00007521	611130	0.124	23	203
602130	CONDUCTOR	Unknown age	#4 Cu strand	0.178	732,149	55	0.00007521	611130	0.124	38	334
612130	CONDUCTOR	< 30 years old	#4 Cu strand	0.139	650,496	38	0.00005873	611130	0.124	34	82

Note the Expected Impact for the current Baseline Risk situation is reduced to the Replacement Risk Expected Impact due to the reduction in expected equipment failure rate. The reduction is risk is calculated over a 20 year planning horizon.

For the initial implementation of the WRRM model, impacts are calculated as the total square footage of each structure lost x 300. This is consistent with calculating the total dollar value for rebuilding structures based a cost per square foot.

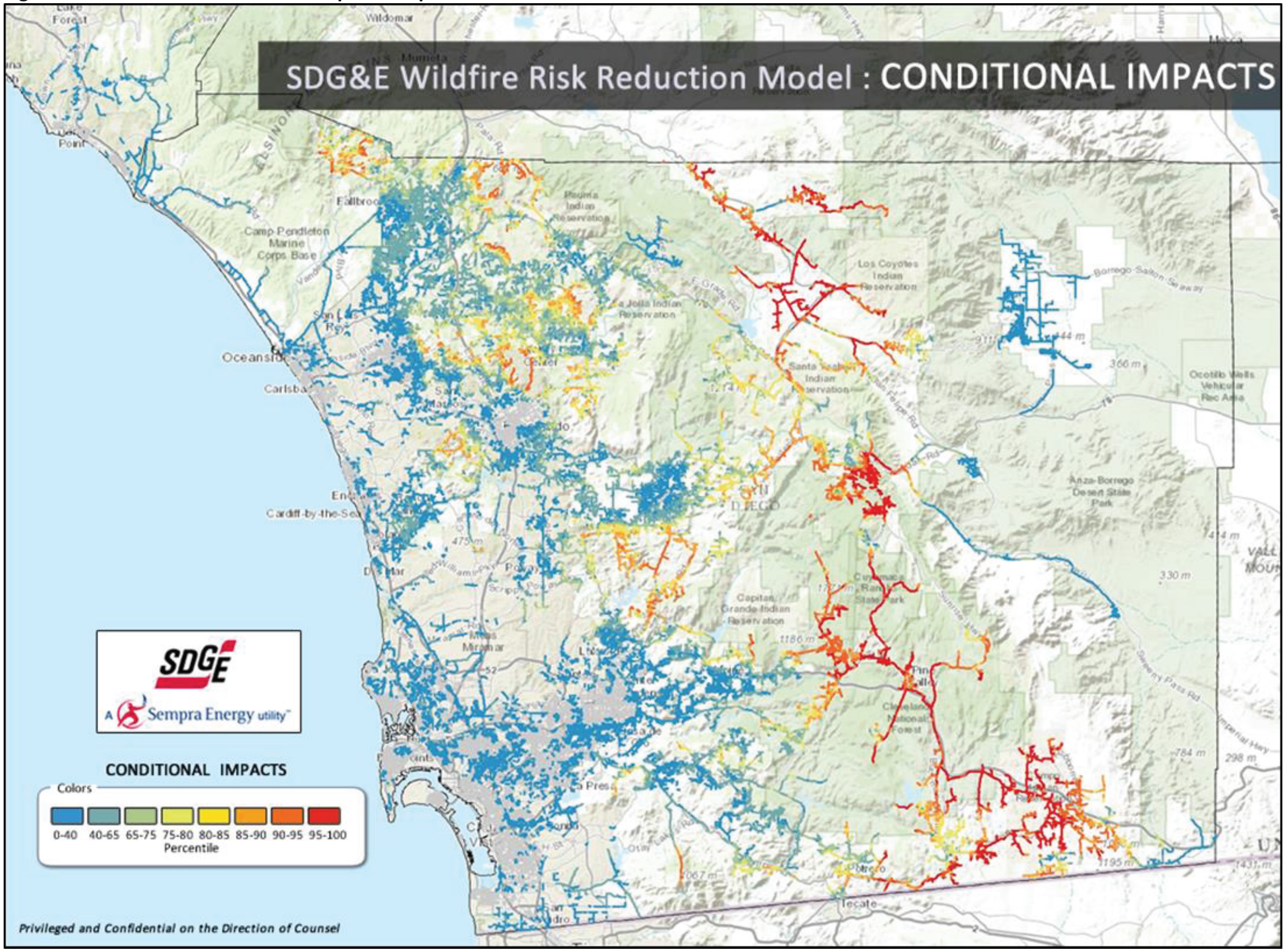
The following figures present maps for the three key outputs. The maps utilize a consistent legend that classify results into 8 classes based on percentiles. This classification provides flexibility for displaying outputs of most concern. The following legend is used:



1. Conditional Impacts Map

The following figure shows the Conditional Impacts map for current assets using the SDG&E GIS assets source data obtained on August 12, 2014.

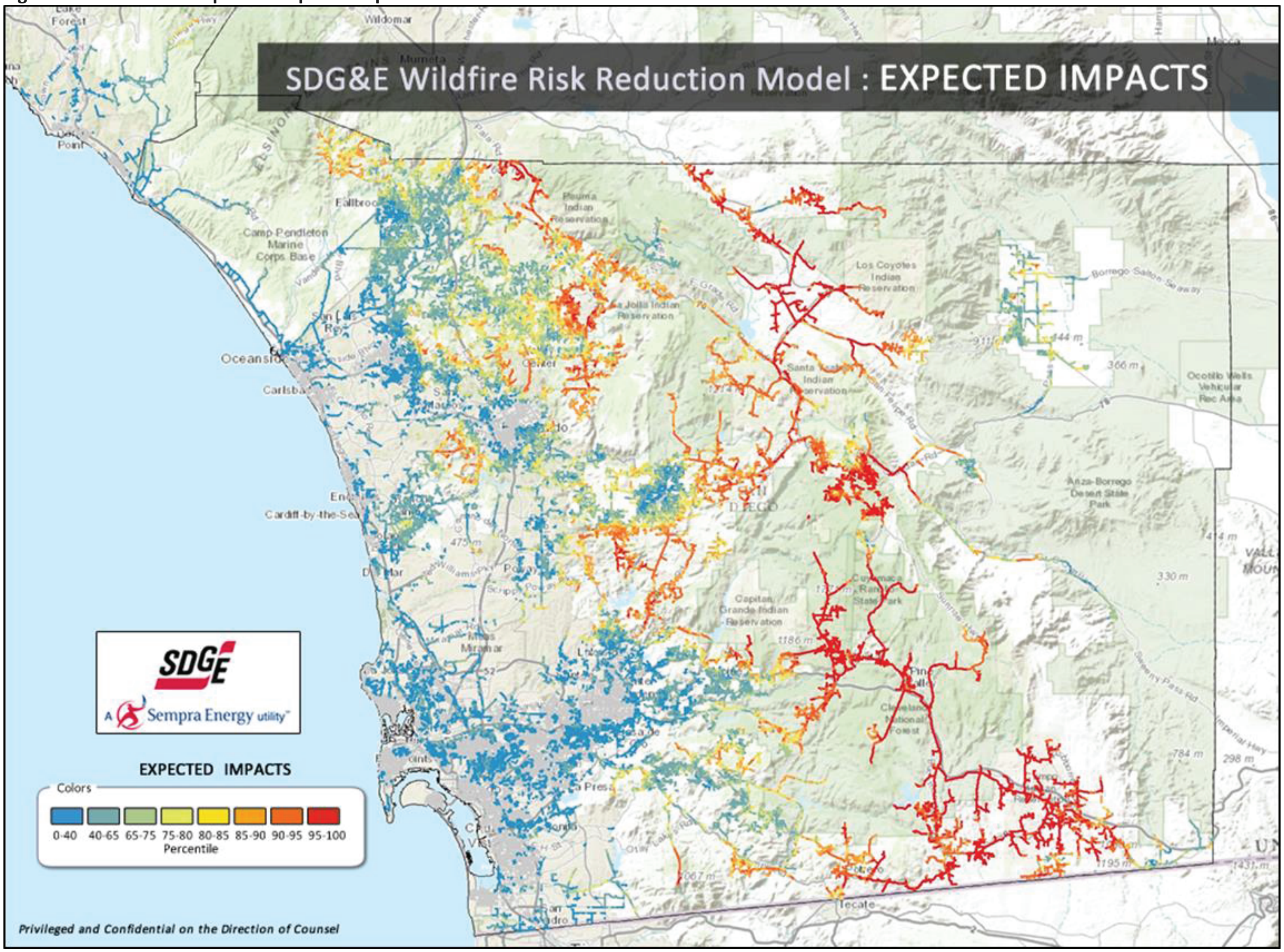
Figure 29. The WRRM Conditional Impacts map.



2. Expected Impacts Map

The following figure shows the Expected Impacts map for current assets using the SDG&E GIS assets source data obtained on August 12, 2014.

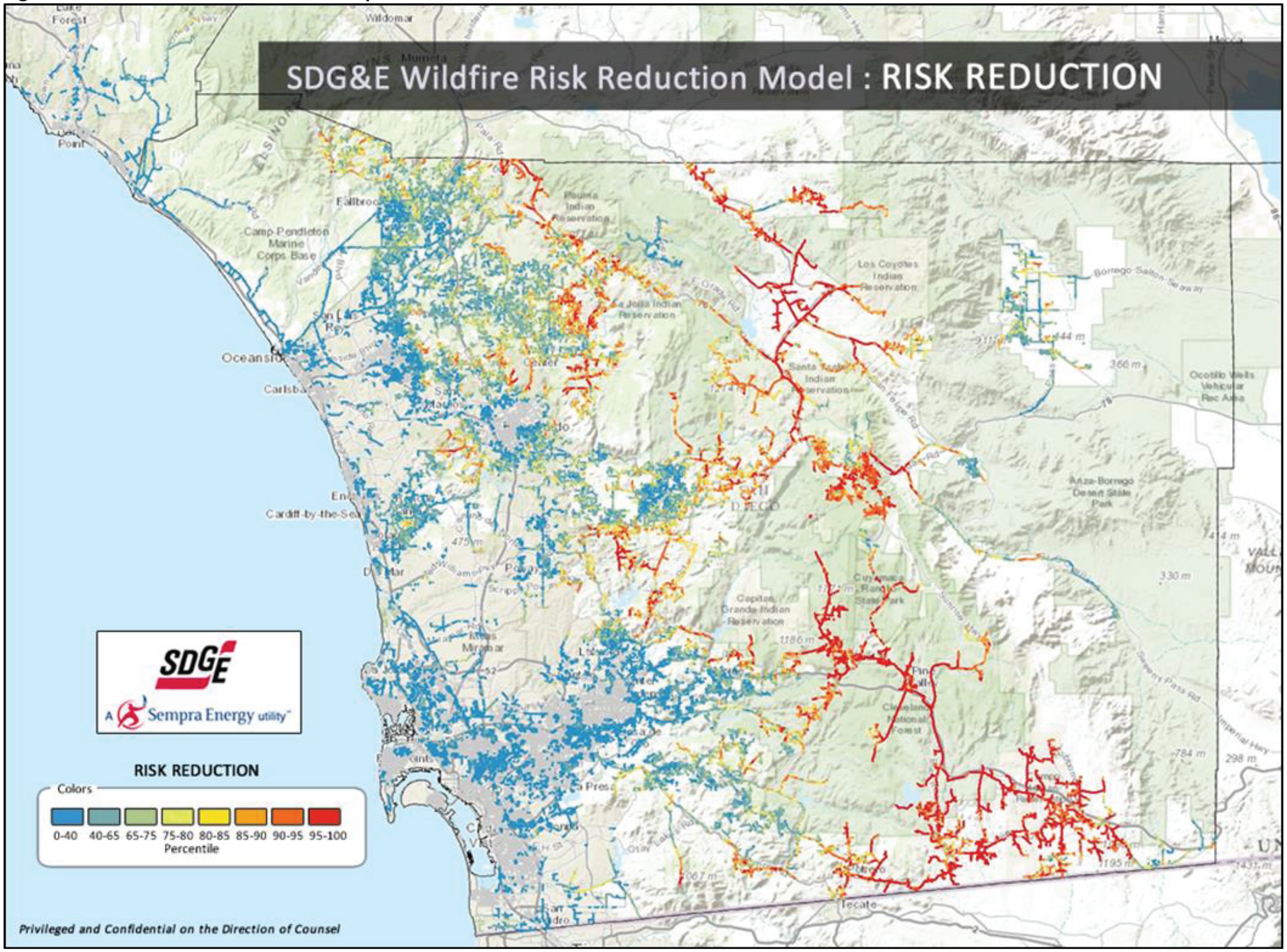
Figure 30. The WRRM Expected Impacts map.



3. Risk Reduction Map

The following figure shows the Risk Reduction map calculated for a 20 year planning horizon for current assets using the SDG&E GIS assets source data obtained on August 12, 2014. This map shows the potential risk reduction based on replacement of assets using a default.

Figure 31. The WRRM Risk Reduction map.



4. Risk Summary Statistics

The WRRM model outputs reflect risk ratings for different assets types within the SDG&E service territory. This section provides a simple statistical summary of the number of assets in each of the different risk classes.

The following tables provide a summary of the total number of assets for each WRRM output by the different percentile classes.

Table 9. Summary of Conditional Impacts for all assets

	Class	Capacitor	Conductor	DPD	Fuse	Poles	Transformer	Total Assets
<=0	0	1,668	107,776	151	27,210	113,261	37,973	288,039
1-40	1	537	49,231	90	8,603	35,442	12,366	106,269
41-65	2	184	28,243	84	5,132	25,702	10,816	70,161
66-75	3	76	11,519	25	1,678	10,797	4,508	28,603
76-80	4	6	5,754	12	674	5,455	2,243	14,144
81-85	5	20	5,892	8	686	5,427	2,093	14,126
86-90	6	21	6,244	23	644	5,320	1,934	14,186
91-95	7	15	6,453	18	516	5,185	1,707	13,894
GT 95	8	24	6,712	18	373	5,073	1,488	13,688
		2,551	227,824	429	45,516	211,662	75,128	563,110

Table 10. Summary of Expected Impacts for all assets

	Class	Capacitor	Conductor	DPD	Fuse	Poles	Transformer	Total Assets
<=0	0	1,668	107,776	151	27,210	113,261	37,973	288,039
1-40	1	78	29,163	47	7,401	57,760	15,112	109,561
41-65	2	102	29,476	101	6,445	23,315	13,384	72,823
66-75	3	83	14,763	35	1,827	7,049	3,780	27,537
76-80	4	71	7,505	21	732	3,553	1,581	13,463
81-85	5	75	7,471	8	803	3,535	1,564	13,456
86-90	6	131	8,647	32	593	2,646	1,208	13,257
91-95	7	127	11,079	25	477	543	452	12,703
GT 95	8	216	11,944	9	28	0	74	12,271
		2,551	227,824	429	45,516	211,662	75,128	563,110

Table 11. Summary of Risk Reduction for all assets

	Class	Capacitor	Conductor	DPD	Fuse	Poles	Transformer	Total Assets
<=0	0	1,668	124,682	429	27,785	116,756	67,141	338,461
1-40	1	371	33,265	0	6,240	47,915	2,042	89,833
41-65	2	130	23,798	0	6,064	23,761	2,436	56,189
66-75	3	89	11,058	0	2,034	7,988	1,293	22,462
76-80	4	57	5,529	0	955	4,174	523	11,238

81-85	5	46	5,839	0	819	3,956	571	11,231
86-90	6	69	5,895	0	753	4,099	417	11,233
91-95	7	55	7,480	0	617	2,707	372	11,231
GT 95	8	66	10,278	0	249	306	333	11,232
		2,551	227,824	429	45,516	211,662	75,128	563,110

5. WRRM Data Maintenance Requirements

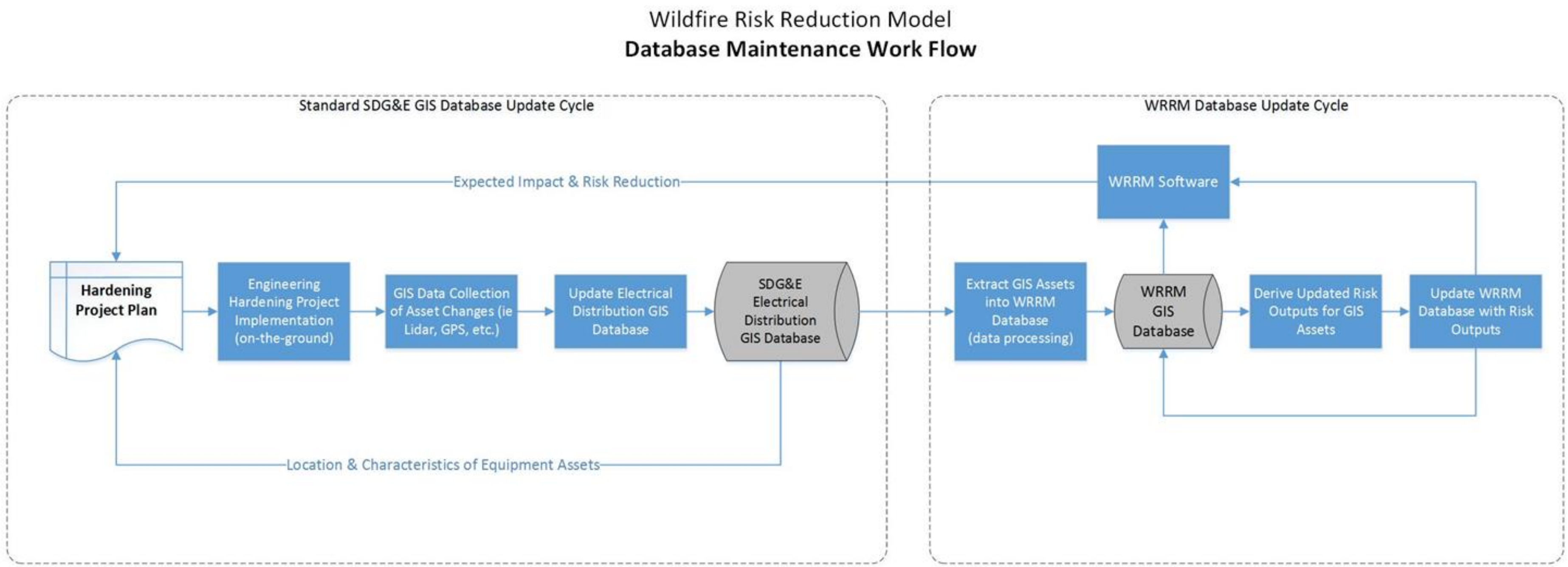
The WRRM model outputs are calculated using the data provided from the SDG&E GIS Assets database. The GIS assets reflects a timestamp of the current conditions of the hardware located across the SDG&E service territory. For example, the initial WRRM model and software used GIS assets data extracted from the SDG&E corporate GIS database on August 12, 2014. As hardening projects are conducted on the ground, assets are replaced changing the condition and characteristics of the assets. Accordingly, the wildfire risk changes (is reduced) as these projects are implemented.

An important aspect of the risk reduction planning process is the updating of the GIS assets database to reflect the changes to asset conditions on the ground, i.e. asset type, size, material, etc. Capturing these updates in the GIS assets database is key to being able to properly calculate the Expected Impacts for the current timestamps as conditions change.

As such, regular updates to the WRRM input database, using the latest SDG&E GIS Assets database, is required to ensure that the WRRM outputs reflect an accurate portrayal of current risk conditions. A regular maintenance process must be employed to ensure that the WRRM database is kept up to date, minimizing the lag time between actual on-the-ground hardware replacements (as-builts) and GIS assets database updates. This will ensure that WRRM outputs reflect current conditions.

The specific “maintenance interval” for updating the WRRM input database is yet to be determined as it is dependent on how quickly the GIS assets database is updated to reflect on-the-ground equipment improvements. An on-going task will be to monitor these updates working closely with the SDG&E GIS Group and FiRM team as part of the WRRM maintenance activities. It is anticipated that updates will be required quarterly, or at least every six months, based on the frequency of hardening project completion. The following figure presents a simple flowchart reflecting the maintenance process that will be required. Note that the WRRM database updating will be fully dependent on the update interval of the SDG&E Electrical Distribution GIS database.

Figure 32. The WRRM database maintenance work flow.



E. Data Processing Methods

The project involved a significant amount of data processing to derive the WRRM outputs used in the WRRM software application. Much of this effort was in the development of the input databases used in the submodels. The following sections provide a description of processing steps.

1. Input Data Processing

The source data for the WRRM model is the SDG&E GIS Assets corporate database. A series of steps were required to utilize the GIS assets data to prepare it for use in the WRRM model. These include:

- Extraction of assets from SDG&E GIS assets corporate database
- Development of possible wildfire ignition points for fire growth submodel
- Development of HVRA input data for vulnerability submodel
- Preparation of asset classes
- Development of asset class lookup table for replacement assets

A detailed description of these steps is provided in Appendix C.

Regular data maintenance to update the GIS assets data will be required to ensure that the results of hardening projects implementation (on-the-ground) is reflected in the GIS Assets data and the WRRM risk outputs. The processing steps identified above will be undertaken for each update.

2. Processing Output Values

Once fire growth model output data was calculated additional data processing steps were required to derive risk outputs for each asset. These steps included:

- Calculating wind factors
- Assigning conditional impacts and wind factors to individual assets
- Calculating expected impacts and risk reduction for individual assets

A detailed description of these steps is provided in Appendix C.

3. Preparing Output Data for WRRM Software

Finally, once all risk outputs were derived some data processing steps were undertaken to create the specific database format required for use in the WRRM software.

- Development of class breaks for conditional and expected impacts, risk reduction outputs
- Development of symbology
- Creation of Esri .geodatabase file (from Esri File Geodatabase format).

A detailed description of these steps is provided in Appendix C.

F. WRRM Software

This section provides a description of the WRRM software deliverable. The WRRM software is a desktop application that encapsulates the WRRM model outputs and provides tools for SDG&E engineers to define hardening projects and evaluate the risk reduction associated with those projects based on the WRRM modeling outputs.

1. Technology Platform

To meet SDG&E security, IT, and operational requirements, the WRRM software application was required to operate on a Windows PC platform as a standalone application. All data must be implemented in a secure manner so that only SDG&E personnel can access the data and no external (Internet) access is possible. The confidential and proprietary nature of the electrical distribution data and risk assessment results dictates this. To satisfy these requirements Technosylva selected the following technology components to optimize performance and capabilities for the WRRM software:

- Windows 7+ OS
- Microsoft Access database for data management
- Esri Arc Run Time SDK for .Net for mapping interface
- Microsoft .NET programming environment for UI development

A key technology selected for the development of the WRRM application is the use of the Esri ArcGIS Run Time SDK.[20] Options existed to develop the WRRM application in the Esri ArcGIS (ArcMap) platform as an extension build using ArcObjects, or the ArcGIS Run Time SDK. The ArcGIS Run Time SDK was selected due to the following technical advantages:

- Licensing - no ArcGIS product licensing required so the application does not require connection to the Esri ArcGIS licensing server, and accordingly does not cost SDG&E in license deployments or fees.
- Map Performance – RT is ideal for mission critical applications that utilize large GIS databases and require fast map performance (query, zoom, pan, feature selection, etc.). The SDG&E GIS Assets contain a large number of features and is approximately 5.4 GB in a conventional ArcGIS File GDB format. Performance when accessing such a large GDB can be slow especially when using the Desktop ArcMap software with mxd documents.
  Using specialized a GIS database format designed for RT, we are able to compress the WRRM GIS Assets database to 273 MB using the RT .geodatabase format. This format ensures very fast map performance even with a large number of features. Given the interactive requirements of the WRRM for asset (feature) selection and query, map performance is a critical functional requirement.
- Installation – no standard Windows installation process is required for the application due to the use of Microsoft and Esri run time development platforms. Accordingly, administrator access is not required to "install" the WRRM software and no direct Microsoft or Esri licensing is required. The baseline for run time technology is the ability to simply drop files onto a computer and run the programs immediately. As such, the WRRM software installation process is extremely simple and accommodates frequent updates to the program and database with no installation overhead.
- Update Flexibility – the RT platform affords flexibility to accommodate frequent updates to the application and the database. With on-going hardening projects occur this is a mandatory requirement.

2. Functional Requirements

As part of the normal course of designing and maintaining its overhead electric system SDG&E's engineers and designers endeavor to regularly analyze circuits to determine and offer hardening and rebuilding projects in order to reduce fire risk and increase reliability. These projects vary widely in cost, complexity, duration and distance. Each project is reviewed by a team of individuals and scheduled to be completed based on available capital as well as perceived risk that is based on a variety of factors and the associated ranking. However, through all this evaluation and risk perception SDG&E's engineers are unable to associate a specific percentage of fire related risk reduction gained by completing these projects.

[20] Please refer to https://developers.arcgis.com/net/ for more information about the ArcGIS Run Time SDK product.

As such, SDG&E desired to develop a risk reduction computer-based modeling program that allows its engineers to evaluate and rank each project to determine the amount of fire risk reduction it would obtain as a result of completing any particular project. This requirement provides the foundation for WRRM functional requirements.

The WRRM software shall provide known and perceived risk measures that will allow SDG&E engineers to rank proposed electric overhead distribution hardening and re-build projects based on value in comparison to risks associated with wildfire. This WRRM software should be PC based and be able to be run by the engineers developing the circuit rebuild projects.

With these core requirements, the following functional requirements were defined for the WRRM software by the SDG&E team.

1. Define an area where a hardening project will occur.
   a. This shall be the first step in identifying potential assets that will comprise a hardening project.

2. Select specific assets (i.e. conductors, poles, capacitors, etc.) for the project.

   a. The selection of assets should utilize the asset characteristics (i.e. size, type, material, age, etc.) as well as the WRRM model risk outputs to aid the engineer.
   b. Tools should be provided to select assets on the map and also in a table showing asset and risk attributes.

3. Define the assets that will replace current assets.
   a. Provide tools to add, remove assets from the project and review the change in risk reduction that occurs.

4. Generate a report that summarizes risk for the current and replacement assets, including the measure of risk reduction for the hardening project.
   a. The report shall be in Excel XLS format to facilitate use in other reports by SDG&E personnel.
   b. Report shall summarize Conditional Impacts, Expected Impacts (for current and replacement asset), and Risk Reduction on a per asset basis, asset class, and for the entire project.

5. Provide interactive mapping interface.
   a. Interface shall allow for viewing the risk outputs, as well as the selection of assets for hardening projects.

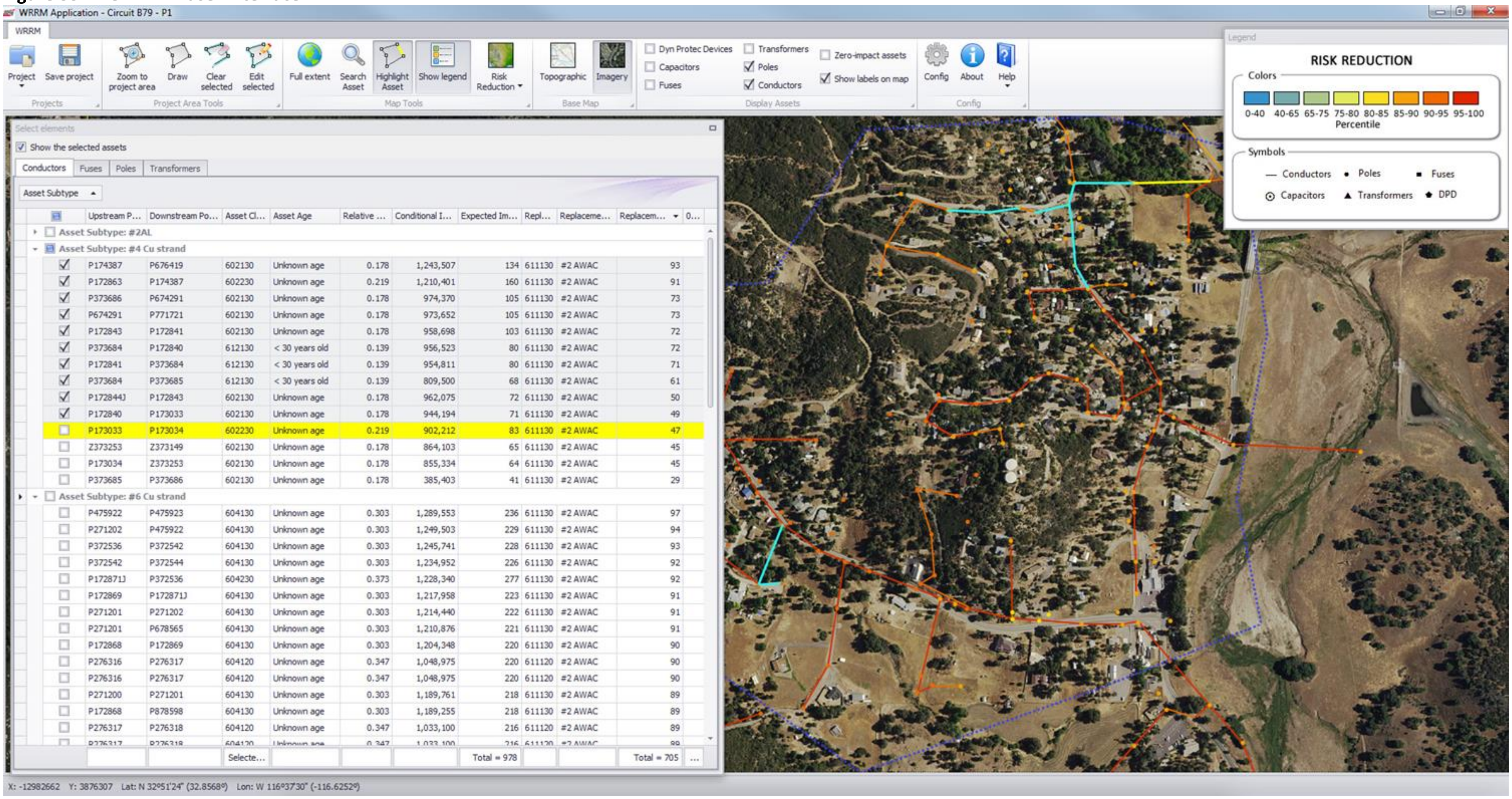
6. Provide data table interface.
   a. Interface shall allow for viewing the data table associated with SDG&E assets and provide capabilities for the user to select specific assets (add/remove) for the active project.

7. Provide supporting documentation and user manual.

The following figure shows the WRRM software application user interface. The functional capabilities are deployed using a main toolbar at the top of the application providing quick and easy access to all capabilities. The main panel is an interactive map that displays the GIS Assets as different map themes over a user selected base map. Topographic and high resolution imagery base maps are available as background information.

A data table showing the data for the user selected hardening project can be positioned based on user preference, either as a floating window or docked to the application frame. Asset data within the table can be sorted and grouped as desired by the user to depict and organize the data to reflect the information considered most important. Fields existing for each data asset with failure rate, Conditional Impact, Expected Impact (current asset), replacement asset, Replacement Expect Impact, and Risk Reduction value.

Figure 33. The WRRM user interface.



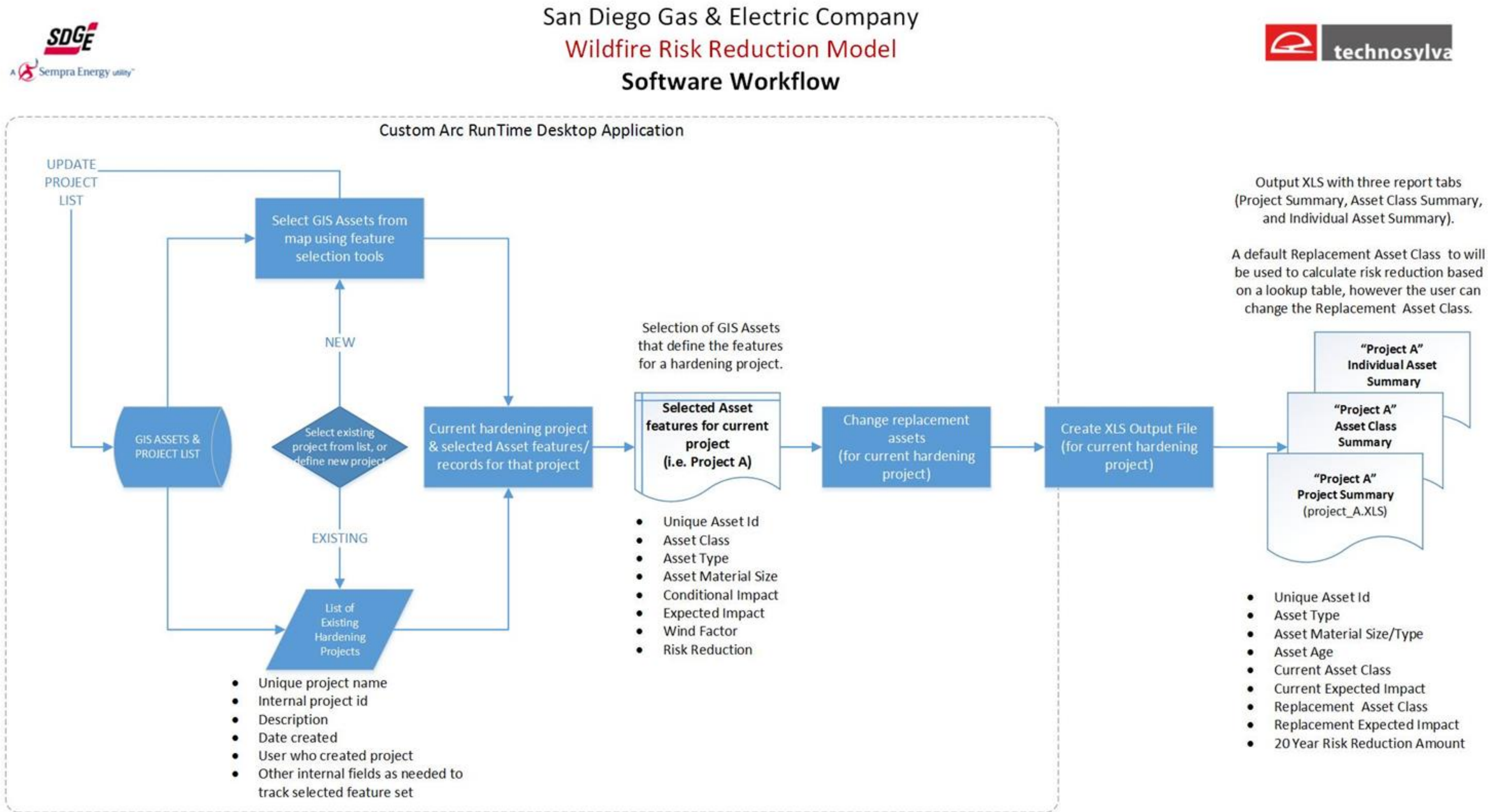
3. Operating Workflow

Based on the definition of functional requirements, the following figure (Figure 34) presents the agreed upon workflow for the WRRM application. The workflow focuses on using the GIS assets database that contains the WRRM risk outputs to define hardening projects by selecting specific assets. This includes the ability to create and store multiple hardening projects. A suite of tools is provided to allow the user to add and remove assets from a specific project.

The design of the WRRM data model inherently includes the key WRRM output fields, i.e. relative failure rate, ignition rate, conditional impact, current asset expected impact, replacement asset class, replacement asset failure rate, replacement expected impact, and risk reduction, in the GIS assets data table. This provides real-time review of risk metrics as projects are defined allowing for the SDG&E engineer to consider the risk outputs in planning the project.

While risk metrics are available in real-time during asset selection for projects, it is necessary to also provide a report generation capability allowing the user to create output reports that summarize the risk. These reports are produced as external Excel XLS files allowing for use of the risk data outside of the WRRM application.

Figure 34. The WRRM software work flow.



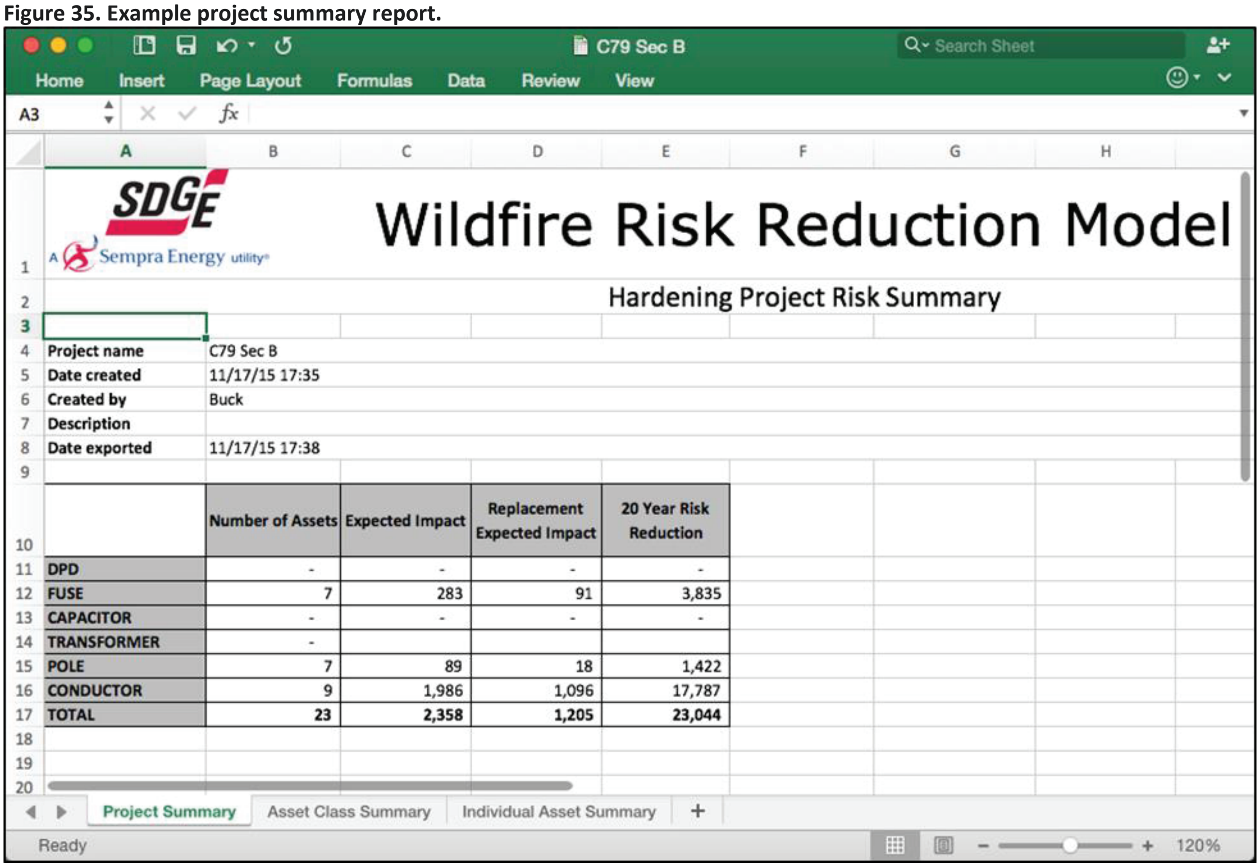
4. Reporting Capabilities

The WRRM application provides the capability for the SDG&E engineer to generate reports in Excel XLS format that quantify risk and risk reduction by:

1. Individual assets within a project
2. Asset classes within a project, and
3. The entire project.

The following figure presents an example hardening project summary report. The project is summarize by asset type and shows the total change in impacts (risk), and the level of risk reduction achieved over a 20 year planning horizon.

Figure 35. Example project summary report.



Wildfire Risk Reduction Model

Hardening Project Risk Summary

Project name	C79 Sec B
Date created	11/17/15 17:35
Created by	Buck
Description	
Date exported	11/17/15 17:38

	Number of Assets	Expected Impact	Replacement Expected Impact	20 Year Risk Reduction
DPD	-	-	-	-
FUSE	7	283	91	3,835
CAPACITOR	-	-	-	-
TRANSFORMER	-			
POLE	7	89	18	1,422
CONDUCTOR	9	1,986	1,096	17,787
TOTAL	**23**	**2,358**	**1,205**	**23,044**

The following figure presents an example hardening project summary report by Asset Class. The project is summarized by asset class (grouping of assets by common characteristics – subtype, age, material, etc.), and shows the total change in impacts (risk), and the level of risk reduction achieved over a 20 year planning horizon.

Figure 36. Example project summary by Asset Class.

Wildfire Risk Reduction Model

Asset Class Risk Summary

Project name	C79 Sec B
Date created	11/17/15 17:35
Created by	Buck
Description	
Date exported	11/17/15 17:38

Baseline Risk							Replacement Risk				
Asset Class	No. of Assets	Asset Type	Asset Age	Asset Subtype	Current Relative Failure Rate	Mean Expected Annual Impact	Replacement Asset	Replacement Relative Failure Rate	Mean Replacement Expected Impact	Mean 20 Year Risk Reduction	Total 20 Year Risk Reduction
602230	4	CONDUCTOR	Unknown age	#4 Cu strand	0.219	237	611130	0.124	134	2,054	8,216
612130	1	CONDUCTOR	< 30 years old	#4 Cu strand	0.139	102	611130	0.124	91	219	219
602130	1	CONDUCTOR	Unknown age	#4 Cu strand	0.178	114	611130	0.124	80	692	692
612230	1	CONDUCTOR	< 30 years old	#4 Cu strand	0.171	164	611130	0.124	119	903	903
604130	2	CONDUCTOR	Unknown age	#6 Cu strand	0.303	329	611130	0.124	135	3,878	7,756
201000	4	FUSE	Unknown age	Kearney QA	1	50	203000	0.3	15	706	2,824
205000	3	FUSE	Unknown age	All other fuses	0.8	27	203000	0.3	10	337	1,011
511400	3	POLE	< 30 years old	Wood pole	0.667	13	512000	0.133	3	208	624
521400	2	POLE	30-40 years old	Wood pole	0.667	6	512000	0.133	1	99	199
541222	1	POLE	> 50 years old	Wood pole	0.667	21	512000	0.133	4	340	340
511222	1	POLE	< 30 years old	Wood pole	0.667	16	512000	0.133	3	259	259

Project Summary | Asset Class Summary | Individual Asset Summary

The following figure presents an example hardening project summary report by individual assets. The project is summarized by each individual asset and shows the total change in impacts (risk), and the level of risk reduction achieved over a 20 year planning horizon.

Figure 37. Example project summary by individual asset.

Wildfire Risk Reduction Model

Individual Asset Risk Summary

Project name	C79 Sec B
Date created	11/17/15 17:35
Created by	Buck
Description	
Date exported	11/17/15 17:38

Baseline Risk										Replacement Risk				
Asset Class	Asset Type	Asset Age	Asset Subtype	Current Relative Failure Rate	Ignition Ratio	Wind Factor	Conditional Impact	Expected Annual Impact	Current Ignition Rate	Replacement Asset	Replacement Relative Failure Rate	Replacement Expected Impact	20 Year Risk Reduction	Replacement Ignition Rate
602230	CONDUCTOR	Unknown age	#4 Cu strand	0.219	0.00120721	0.35	2,476,116	229	0.00009253	611130	0.124	130	1,985	0.00005239
612130	CONDUCTOR	< 30 years old	#4 Cu strand	0.139	0.00120721	0.35	1,732,245	102	0.00005873	611130	0.124	91	219	0.00005239
602130	CONDUCTOR	Unknown age	#4 Cu strand	0.178	0.00120721	0.35	1,518,915	114	0.00007521	611130	0.124	80	692	0.00005239
602230	CONDUCTOR	Unknown age	#4 Cu strand	0.219	0.00120721	0.35	2,541,710	235	0.00009253	611130	0.124	133	2,038	0.00005239
602230	CONDUCTOR	Unknown age	#4 Cu strand	0.219	0.00120721	0.35	2,516,301	233	0.00009253	611130	0.124	132	2,017	0.00005239
602230	CONDUCTOR	Unknown age	#4 Cu strand	0.219	0.00120721	0.35	2,714,830	251	0.00009253	611130	0.124	142	2,176	0.00005239
612230	CONDUCTOR	< 30 years old	#4 Cu strand	0.171	0.00120721	0.35	2,276,601	164	0.00007225	611130	0.124	119	903	0.00005239
604130	CONDUCTOR	Unknown age	#6 Cu strand	0.303	0.00120721	0.35	2,356,025	302	0.00012802	611130	0.124	123	3,558	0.00005239
604130	CONDUCTOR	Unknown age	#6 Cu strand	0.303	0.00120721	0.35	2,780,326	356	0.00012802	611130	0.124	146	4,198	0.00005239
201000	FUSE	Unknown age	Kearney QA	1	0.00003562	0.6	2,771,279	59	0.00002137	203000	0.3	18	829	0.00000641
205000	FUSE	Unknown age	All other fuses	0.8	0.00003562	0.6	1,576,436	27	0.0000171	203000	0.3	10	337	0.00000641
201000	FUSE	Unknown age	Kearney QA	1	0.00003562	0.6	1,949,380	42	0.00002137	203000	0.3	13	583	0.00000641
201000	FUSE	Unknown age	Kearney QA	1	0.00003562	0.6	1,949,380	42	0.00002137	203000	0.3	13	583	0.00000641
201000	FUSE	Unknown age	Kearney QA	1	0.00003562	0.6	2,771,279	59	0.00002137	203000	0.3	18	829	0.00000641
205000	FUSE	Unknown age	All other fuses	0.8	0.00003562	0.6	1,576,436	27	0.0000171	203000	0.3	10	337	0.00000641
205000	FUSE	Unknown age	All other fuses	0.8	0.00003562	0.6	1,576,436	27	0.0000171	203000	0.3	10	337	0.00000641

Project Summary | Asset Class Summary | Individual Asset Summary

Resilience Plan for Sea Level Rise

I. Electric Sector Vulnerability Studies and Adaptation Options to Promote Resilience in a Changing Climate

A. Introduction

The work outlined in the sections to follow is part of a two-year project with ICF International that aims to establish an understanding of the electricity sector's vulnerability to coastal hazards, sea level rise (SLR), and coastal climate change impacts in the San Diego Gas & Electric (SDG&E) service territory within the next 10-30 years and beyond, and to identify potential adaptation options. By identifying the vulnerabilities and physical processes causing the vulnerabilities, this project, which is funded by a California Energy Commission grant, aims to identify practical and decision-focused analysis of the various adaptation strategies at a level of detail appropriate for informing electricity sector policy and planning.

To convey work efforts, the sections to follow are structured into four sections: 1) **Purpose**- *what was the reason for the task*; 2) **Methodology**- *what was the plan to complete the task*; 3) **Research**- *what did we find*; and, 4) **Conclusion**- *what does this mean moving forward*. The Research Section is divided into three parts: 1) Review existing coastal hazards efforts, including **sea level rise (SLR)**; 2) Develop knowledge of sensitivity of **assets and operations**; and, 3) Identify recommended and/or considered **adaptation measures**.

B. Purpose

Although this project is focused on the SDG&E's electric service territory, the purpose of this task is to conduct a comprehensive review of widespread material and information to ensure that the project builds on the latest research regarding electricity sector vulnerability to select coastal hazards in an effort to identify potential adaptation measures. In doing so, gaps in the current state of knowledge of electricity sector vulnerability to coastal hazards will also be uncovered. By identifying the vulnerabilities (and physical processes causing those vulnerabilities), practical, decision-focused analysis can be conducted at a level of detail appropriate for informing planning, program, and policy decisions. It can also aid in the identification of SDG&E-specific adaptation measures and strategies.

C. Methodology

A multifaceted approach was implemented to ensure that the review of material and information was comprehensive and germane to the scope of the project. The first step was to establish a list of "*key words*" and "*key phrases.*" With this list of "*key words*" and "*key phrases,*" ICF conducted a literature search using the Elton B Stephens Company (EBSCO) Host Research Databases, the California Natural Resources Agency "*Planning for Sea Level Rise*" database (AB2516, Gordon), and general internet searches using Google and other search engines. The EBSCO Host Research Databases provided ICF with a list of relevant worldwide published documents, reports, and studies, while ICF used the *Planning for Sea Level Rise* database to identify California-specific studies, assessments, and programs aimed at addressing sea level rise. General searches on the internet provided ICF with a list of published and unpublished documents, reports, and studies, and links to relevant projects, presentations, and articles.

This effort was supplemented by coordination with our Technical Advisory Committee (TAC) group (made up of climate change experts) and our Stakeholder group (comprised of California utilities and regional/local government representatives). At the start of the effort, ICF held a meeting with the TAC and Stakeholder groups to introduce group members to the project and solicit their feedback on the project and task approach. Another benefit of the meeting was to request them to identify (and if possible provide) essential material (i.e., documents, reports, and studies) they believe should be considered as part of this project. The group members were not all centrally located, since ICF saw value in convening diverse TAC and Stakeholder groups that could provide insight into the current best-practices in climate change adaptation. Due to logistical complications, competing priorities, and budgetary constraints, it was determined best to conduct meetings via conference call where ideas and material could be exchanged and shared, instead of in-person meetings.

Members of the ICF team also provided relevant material, drawing from: 1) current and past efforts, 2) other meetings and conferences, and 3) general experience in the subject areas. An example of this is the leveraging of recently produced climate-related studies by utility companies. As part of the requirement under the U.S. Department of Energy (DOE) Partnership for Energy Sector Climate Resilience,[21] partnering utility companies were requested to submit vulnerability assessments. The ICF team reached out to a variety of utility companies to obtain copies of their DOE-requested vulnerability assessments. While our contact with some of the utility companies was focused on obtaining the DOE vulnerability assessments, we also inquired about other material that might be of use for the project and our efforts (i.e., regulatory filings, design standards).

The ICF team augmented the literature research with expert interviews. The interviews were used for three purposes: 1) to validate findings, 2) to fill knowledge gaps, and 3) to understand concurrent 4th Climate Change Assessment efforts. Information learned from the interview process is included in the relevant research sections: 1) Existing coastal hazards efforts, including sea level rise (SLR); 2) Knowledge of sensitivity of assets and operations; and 3) Recommended and/or considered adaptation measures. The ICF team met with various climate change experts and representatives from electricity utility companies (both in California and across the country) to get a better sense of key, relevant efforts and available information. To serve as an aide during the interviews and promote consistency, the ICF team developed a list of questions to help gain a better understanding of how climate change vulnerability was being addressed (Appendix D). The ICF team also met with Project Managers working on projects under the 4th Climate Change Assessment. Through the CEC and the Natural Resources Agency (NRA), ICF attended several workshops, conference calls, and follow up meetings with Project Managers from various CEC and NRA 4th Climate Change Assessment projects.

D. Research

The goal at the outset of the research effort was to establish a solid understanding of the work being done on climate change broadly and SLR in particular, with a focus on what is being done in the San Diego area. The ICF team initially searched for assessments that had been undertaken at a state-wide level (e.g., the Pacific Institute (2009) analysis of the potential impacts of SLR on the coast of California) and then refined the analysis specifically to those studies that have assessed impacts within SDG&E's service territory. The research uncovered a range of material from assessments to strategic plans to guidance documents. Each of these provided additional insight into the considerations, influences, and factors of coastal hazards.

Below is a summary of the more relevant completed climate change and/or SLR assessments or plans specific to the San Diego region reviewed by the ICF team:

- *SLR Adaptation Strategy for San Diego Bay,* International Council for Local Environmental Initiative (ICLEI): a regional, collaborative, stakeholder process undertaken as part of the San Diego Regional Climate Protection Initiative, a partnership with the San Diego Foundation and all local governments in the San Diego region, which consists of a vulnerability assessment that evaluates how community assets could be impacted by SLR, as well as recommendations for building the resilience of those community assets.
- *Climate Adaptation Plan Strategies* in 2011 (City of Chula Vista, 2011): a high-level vulnerability assessment completed and adopted in 2010 that informed the City's involvement in the ICLEI study (above).
- *Climate Action Strategy*, The San Diego Association of Governments (SANDAG): a climate action strategy to identify land use and transportation policy measures that could help SANDAG meet or exceed its Senate Bill 375 (Steinberg, Chapter 728, Statutes of 2008) targets for reducing Greenhouse Gases (GHG) from passenger cars and light-duty trucks.

[21] http://energy.gov/epsa/partnership-energy-sector-climate-resilience

- *Regional Focus 2050 Study,* The San Diego Foundation: explores what the San Diego region will be like in the year 2050 if current climate trends continue, based on projections of climate change generated by scientists at Scripps Institution of Oceanography (SIO).
- *San Diego, 2050 is Calling,* Climate Education Partners (CEP): part of an effort to develop and implement a climate change education plan for the San Diego region, this report identifies key climate hazards and the implications of their potential impacts in the San Diego area.
- *A methodology for assessing the impact of sea level rise on representative military installations in the Southwestern United States,* The Space and Naval War Systems Command (SPAWAR): a SLR and coastal hazard vulnerability study focused on the Pendleton Marine Corp Base and Coronado Naval Base (Chadwick, 2014). The study utilizes a series of models to evaluate long term shoreline seasonal beach changes, and used the results of change models to iteratively project the extent of future coastal flood, erosion, and tidal inundation.
- *Draft Fee Study for Shoreline Protective Devices,* The City of Solana Beach (2015): aims to (a) establish a methodology to quantify beach value and determine an impact mitigation fee to compensate the public for recreational loss associated with the installation of shoreline protective devices, and (b) provide an analysis of potential offsets to this fee, such as public safety benefits. The study includes sea level rise projections through 2050 along with an analysis of the projected impacts of sea level rise impacts on bluff erosion.
- The *Integrated Feasibility Report and Environmental Impact Statement/Report (EIS/EIR)* for the *Encinitas-Solana Beach Coastal Storm Damage Reduction Project* was prepared to identify and evaluate potential environmental impacts incurred from the proposed project. SLR scenarios for the Encinitas and Solana Beach areas were used to establish the requirements for various protection measures to mitigate coastal erosion-induced storm damage between 2018 and 2068.

In addition to the above, the ICF team reviewed a number of vulnerability assessments and planning processes underway throughout the region. Below is a summary of the more relevant work:

- The City of Imperial Beach is conducting a vulnerability assessment, economic analysis, and adaptation planning (Revell Coastal, 2016) focused on vulnerability to coastal flooding, nuisance flooding, and tidal inundation based on the climate-related variables of sea level, wave height, and extreme tides. Adaptation planning includes an examination of a suite of potential alternatives including managed retreat, armoring, nourishment, living shorelines, and groins using a holistic cost benefit analysis and modeling of physical response to the proposed adaptation strategies.
- The City of Del Mar is in the process of developing a coastal hazard vulnerability and risk assessment, and has released a draft document. The assessment focuses on vulnerability to coastal flooding, bluff erosion, and river flooding, and is based on climate-related variables of sea level, wave height, precipitation and river flow (ESA, 2016). A combination of observed impacts from historic extreme events and projections for future extreme events are being used to evaluate vulnerability (ESA, 2016). The City is currently in the process of developing and selecting adaptation options.
- The City of Carlsbad is in the process of developing a coastal hazard vulnerability and risk assessment. The assessment focuses on vulnerability to coastal flooding, bluff erosion, and river flooding, and is based on the climate variables of sea level, wave height, precipitation and river flow available from Coastal Storm Modeling System (CoSMoS) 3.0. This also includes analysis of storm drain systems and the three lagoons within the City of Carlsbad. This report is expected to be released in September 2016.

SDG&E is a member of the San Diego Climate Collaborative (SDCC) Sea Level Rise Working Group, a network for public agencies that serve the San Diego region to share expertise, leverage resources, and advance comprehensive solutions to facilitate climate change planning. The SDCC serves as a point of contact and networking platform for communication between cities and other critical infrastructure when planning for sea level rise. The SDCC has also received a NOAA Coastal Resiliency Grant. This grant-funded project includes a county-wide vulnerability assessment to be completed by ICLEI, and a San Diego River coastal confluence modeling study to be completed by Revell Coastal. Expected grant completion is March 2017.

ICF reviewed a select number of energy utility vulnerability assessments, addressing either projected climate impacts, existing extreme weather hazards, or both. While the review focused on assessments from major California energy utilities (i.e., Pacific Gas and Electric- *PG&E*, Southern California Edison- *SCE*, Sacramental Municipal Utility District- *SMUD*, and SDG&E), it also included a selected number of vulnerability assessments from utilities outside of California, including Consolidated Edison (Con Edison) and Seattle City Light. The review uncovered varying degrees of analysis, with most discussing vulnerability at the larger system level. The documents also used a variety of SLR and climate hazard scenarios.

The ICF team also held a series of conference calls with representatives from a variety of electricity utility companies. The purpose of the meetings was to provide further insight into their climate change efforts and, in particular, their recent work on climate change vulnerability assessments (including the identification of key assets and operations). The calls uncovered the types of climate change hazards they researched, the scenarios/drivers used, challenges faced in completing the work, and next steps. The ICF team spoke with representatives from Public Service Electric and Gas (PSE&G), SCE, SMUD, PG&E, and Con Edison.

Follow up meetings were also conducted with select members from the TAC Group, the San Diego Regional Climate Collaborative (Laura Engeman) and the San Diego Foundation (Nicola Hedge), to gain a broader perspective on work being done in the San Diego region. The meetings provided greater awareness of the data currently being used, challenges in leveraging and incorporating the data, limitations of the data, and missing data.

The following sections provide a summary of the focused research areas.

1. Coastal Hazards

Research under this subtask focused on understanding:

- projections of SLR for California and the local San Diego area; and
- key issues of changes to coastal processes.

The research also led the ICF team to identify available information on coastal hazard models.

Sea Level Rise

The National Research Council (NRC) of the National Academies (2012) summarize the state of the science SLR scenarios for Washington, Oregon, and California. The study identified suitable regional projections based on the best available science available at the time. Table 12 provides a summary of the NRC SLR ranges (the possible but unlikely upper and lower bound) and projections (the most likely value) for the area of California south of Cape Mendocino (City and County of San Francisco 2015).

Table 12. Regional SLR ranges and projections for California south of Cape Mendocino (NRC 2012)

Time Period*	SLR Range (B1-A1FI scenario)	Projection: Los Angeles, CA (A1B scenario)
By 2030	2 – 12 in (4 – 30 cm)	6 ± 2 in (15 ± 5 cm)
By 2050	5 – 24 in (12-61 cm)	11 ± 4 in (29 ± 9 cm)
By 2100	11 – 66 in (42 – 167 cm)	37 ± 10 in (93 ± 25 cm)

*relative to the year 2000

In 2015, the California Coastal Commission (CCC) released a policy guidance document, *Sea Level Rise Policy Guidance: Interpretive Guideline for Addressing Sea Level Rise in Local Coastal Programs and Coastal Development Permits* (CCC 2015), which lays out their expectations for incorporating SLR into Local Coastal Program updates and coastal development permits. The document recommends the use of the NRC 2012 SLR scenario ranges (see Table 12).

The ICF team interviewed Dr. Dan Cayan from Scripps Institution of Oceanography to discuss available SLR data and scenarios. Dr. Cayan is leading a CEC-funded 4th Climate Change Assessment grant project to develop probabilistic regional SLR scenarios. Dr. Cayan recommended that the project team use these data, when released, as the basis for the sea-level rise exposure analysis. Dr. Cayan based this recommendation on the fact that the new data will make use of the latest understanding of the specific inputs into the SLR scenarios, including ice sheet-melt dynamics. The California Energy Commission is utilizing Dr. Cayan's work to help defining common SLR recommendations. These recommendations will be considered once available.

Coastal Processes

Coastal Erosion

Research indicates that cliff erosion in San Diego is driven primarily by coastal processes (e.g., wave run-up and tides) and precipitation (Young and Ashford 2006). Gullying during rain events can cause substantive erosion of the cliffs and add significant volumes of sand to the littoral system. Additional research indicates high wave energy seasons would cause excessive erosion above average while reduced wave energy conditions would result in a wider beach and more seaward shoreline location. Such changes to the coastline can have significant effects on the extent and depth of temporary and permanent inundation associated with SLR and storm events (Yates et al. 2009).

Wave Run-up

Wave run-up is the maximum vertical extent of wave uprush on a beach or structure above the still water level (Sorensen, 1997). Recent research suggests that dynamic wave run-up calculations, including the time varying run-up (e.g., calculations included within the Xbeach and Eurotop models), performed better than empirical total water level calculations (i.e., wave overtopping and flood extent mapping). Other material on this topic calibrated a total water level run-up equation based on observed measured wave run-up elevations from research around the country (Stockdon, Holman, Howd, and Sallenger 2006). Wave height increases can magnify the impact of SLR, increasing the extent of coastal inundation, erosion, and associated electric asset exposure.

Tidal Inundation

Tidal flooding—coastal flooding that occurs during tidal conditions not associated with coastal storms or heavy rainfall—can overwhelm storm drains, cause road closures, and deteriorate infrastructure (National Oceanic and Atmospheric Administration-NOAA 2014). Gradual local SLR, particularly if combined with the loss of natural coastal barriers, may increase the frequency and/or the extent of impacts for tidal or continuous flooding (NOAA 2014), which may introduce new risks to electricity service and assets. For some locations, "king tides" (the highest predicted high tide of the year at a coastal location) may provide an example of conditions that will occur more frequently in the future because of SLR.

Coastal Hazard Models

The Coastal Storm Modeling System (CoSMoS) is a multi-agency effort led by the United States Geological Survey (USGS) to make detailed projections (2 meter horizontal resolution) of coastal flooding and erosion based on existing and future climate scenarios for Southern California. The current version of modeling effort (v 3.0 preliminary release in November 2015) depicts coastal flooding, shoreline change, and potential cliff erosion response to a 100-year wave event in combination with various elevations of SLR and baseline water levels (i.e., high tide, storm surge, sea level anomaly and river discharge). The USGS has produced results from four SLR scenarios: 50 cm (0.5 m), 100 cm (1.0 m), 150 cm (1.5 m) and 200 cm (2.0 m). It is important to note that the preliminary CoSMoS 3.0 release includes a certain set of assumptions regarding the ongoing existing mitigation actions or projects (e.g., assuming that prior coastal nourishment efforts will continue in the future). The final CoSMoS 3.0 data will include scenarios that include different sets of assumptions. Therefore, the actual inundation and erosion results from the final CoSMoS 3.0 release could be higher in some areas and lower in others than the preliminary data.

The ICF team met with the USGS team to discuss the work being performed on CoSMoS 3.0. Revisions to CoSMoS 3.0 are expected in the early fall of 2016, and anticipated to include 40 scenarios based on 25 centimeter increments (between 0-2 m) and a 5 meter SLR scenario. In addition, it will combine SLR with storm return period scenarios (no storm, annual, 20 year, and 100 year storm scenarios). This will be a significant improvement to the preliminary data release. The USGS team also informed the ICF team that CoSMoS 3.0 is planned to provide better consideration and integration of concurrent processes (coastal erosion, wave run-up) to better estimate potential flooding impact.

The Federal Emergency Management Agency (FEMA) has also developed a flood (coastal flooding) Loss Estimation model called Hazus. The Hazus model is often used to estimate potential damage from coastal floods and is a practical tool for planning purposes. The Hazus model does not take into account climate change variables; however, the model is able to import hazard data that is reflective of climate change considerations. Similarly, the damage estimates are based on 2010 Census information but the model is able to import customized data sets that enable users to gain a greater understanding of more realistic impacts.

2. Assets and Operations

The research for electric assets and operations centered on understanding the sensitivity of specific electric assets and operations and their implications for the function on the electric system as a whole. The approach includes identifying key (critical) electric asset types and operation functions and then providing details on sensitivities identified through the literature review and interviews.

SDG&E's electric system is a complex network of generation, transmission, and distribution components. The ICF team identified several general groups of key asset and operations types based on knowledge of electric systems and review of utility vulnerability assessments (Table 13).

Table 13. Key electric asset and operation types

4 Key Asset Types	Generation	• Generator/Turbine units • Back-up power supply sources • Cooling water intake structures • Distributed generation units (e.g., Photovoltaic panels, wind turbines)
	Transmission	• Long-distance transmission wires and towers
	Distribution	• Distribution transformers • Switches • Feeder circuits • Primary circuits • Overhead wires and poles • Underground wires

	Substations	• Circuit breakers • Switches • Relay panels • Marshalling cabinets • Back-up batteries or power source • Transformers • Protection/control equipment • Underground cables
	• Communications & IT Equipment	
Key Operations Types	• Emergency Response • Communications • Demand Forecasts & Long-Range Planning • Day to day grid operations	

Electric systems, including specific assets and operations, may be sensitive to climate-related hazards. Sensitivity is defined as the degree to which the asset or operation could be impacted by a hazard if exposed. Design standards and guidance that specifically include climate change considerations do not exist. Existing standards and awareness of how existing assets are impacted by current climate hazards (i.e., their sensitivity) facilitates assessment of what future climate conditions will exceed critical thresholds. Historic performance of assets in response to climate-related hazards can also reveal key sensitivities and adaptive capacity (the degree to which an asset or operation can adjust to potential impacts, quickly recover, and take advantage of opportunities).

California utilities must adopt the California Public Utilities Commission's (CPUC's) 2012 General Order 95 (GO95) temperature, wind, and ice condition standards (Table 14). However, these standards do not account for potential changes in future conditions due to climate change. This review did not identify thresholds for other climate variables that incorporate future conditions in California. For example, this review did not find general standards or information on the future depth of inundation that will lead to a power outage at a particular electricity substation of a specific design. It is possible that this information is not found within the literature because it would require extensive data collection and detailed analysis, specific to individual assets and the asset locations (Savonis, Burkett, & Potter, 2008).

Table 14. CPUC General Order 95 Standards

	WIND CONDITIONS	ICE	TEMPERATURE
HEAVY LOADING (ELEVATION >3000 FT.)	• 6 lbs./sqft on cylindrical surfaces • 10 lbs./sqft on flat surfaces • For latticed structures, increase exposed area 1.5x	Radial thickness of 1.5 in. ice (57 lbs./ft3) on all conductors	Assume 0°F temp at max loading; Assume 130°F temp to compute sag & effect on structural loads

LIGHT LOADING (ELEVATION <3000 FT.)	• 8 lbs./sqft on cylindrical surfaces • 13 lbs./sqft on flat surface • For latticed structures, increase exposed area 1.5x	No ice loading	Assume 25°F temp at max loading; Assume 130°F temp to compute sag & effect on structural loads

Table 15 provides a summary of available public information on the types of impacts that can be expected due to sensitivity of assets and operations exposure to coastal hazards (SDG&E specific asset sensitivities will be determined in Task 3; see Conclusion section below). It also provides information on potential adaptation measures.

Table 15. Types of impacts due to sensitivity for assets and operations and potential adaptation measures

			SLR & Coastal Hazard Impacts	Potential Adaptation Measures
Key Asset Types	**Generation**	Generator/Turbine units Back-up power supply sources Cooling water intake structures Distributed generation units (e.g., Photovoltaic panels, wind turbines)	Direct damage from flooding Power outages Temporary or permanent lack of accessibility	Elevate key components Install improved pumping equipment & back-up generators to remove water that intrudes Alter hydroelectricity storage and release strategies Reinforce floodwalls Build or rebuild assets in a new location Build new floodwalls and storm surge barriers Integrate coastal wetlands restoration to protect coastal power plants
	Transmission	Long-distance transmission wires and towers	Direct damage to towers from floating debris during periods of inundation Scour around pole foundation and erosion Temporary or permanent lack of accessibility	Install stabilizing features Reinforce floodwalls Build new floodwalls and storm surge barriers Integrate coastal wetlands restoration to protect coastal powerlines
	Distribution	Distribution transformers Switches Feeder circuits Primary circuits Overhead wires and poles Underground wires	Direct damage to towers from floating debris during periods of inundation Scour around pole foundation and erosion, underground cabling exposed to water movement Coastal underground wire corrosion due to saltwater intrusion from SLR Damage due to water following electrical lines to underground conduits and vaults Temporary or permanent lack of accessibility	Reinforce floodwalls Use submersible equipment Integrate coastal wetlands restoration to protect coastal distribution lines

	Substations	Circuit breakers Switches Relay panels Marshalling cabinets Back-up batteries or power source Transformers Protection/control equipment Underground cables	Direct damage to substation components from floating debris during periods of inundation Damage from corrosion or contaminant deposition of equipment Damage due to water following electrical lines to underground conduits and vaults Power outages for substation control equipment	Elevate stations or key components Reinforce floodwalls Use submersible equipment Build or rebuild assets in a new location Build new floodwalls and storm surge barriers Integrate coastal wetlands restoration to protect coastal stations
	Communications & IT Equipment		Direct damage from flooding Permanent inundation Temporary or permanent lack of accessibility	Develop backup solutions for communications systems remotely monitoring & controlling electricity systems Expand use of water-resistant fiber-optic communications and control systems (as opposed to copper wires) enabling for remotely operated equipment during flooding
Key Operations Types	**Emergency Response**			Review existing protocols and policies for climate change considerations De-energizing equipment in flood zones Preposition equipment, resources, and supplies Participating in Mutual Assistance Groups
Key Operations Types	**Communications**			Upgrade control centers & communication equipment Communicate with fellow employees about potential areas where the system might experience power outages
Key Operations Types	**Demand Forecasts & Long-Range Planning**			Purchase large mobile generators (i.e., Gensets) and transformers to help recover more quickly from power losses Integrate system changes to enhance resilience in long-range asset planning, including revised design standards such as height above Base Flood Elevation for critical assets Increase energy efficiency to reduce electricity demand, and diversifying resource portfolios to minimize risk

			from impacts to any one resource Improve the flexibility of the electric distribution system, including the installation of additional switches and related smart grid technology and the reconfiguration of certain networks to reduce the impact to customers most affected by certain storms Create new or modified indemnity-based insurance
	Day to Day Grid Operations		Review existing protocols and policies for climate change considerations Improve coordination with Independent System Operator and regional bulk power system participants

As part of Tasks 4 (Direct Impacts) and 5 (indirect Impacts), consideration will also be given to asset and operation dependencies and interdependencies (i.e., need for water, electricity, and natural gas) to explore possible cascading sensitivities that could impact maintaining functionality.

The interviews with the utility companies confirmed that, during the DOE vulnerability assessment development process, many undertook the effort at a strategic level for the purpose of planning and analysis, as a means of engaging staff across the utility on the issue of climate change. Many utilities indicated in their vulnerability assessments a need, through additional studies, to consider climate change impacts at an asset-by-asset and operational level. Interviews conducted with utilities impacted by Superstorm Sandy provided insights into the detailed asset-by-asset analysis undertaken to plan for, and to prioritize, the response to the specific flood impacts due to storm surge.

3. Preliminary Results

As discussed above, the USGS has produced preliminary results of the Coastal Storm Modeling System (CoSMoS) from four SLR scenarios: 50 cm (0.5 m), 100 cm (1.0 m), 150 cm (1.5 m) and 200 cm (2.0 m). While different assumptions and more detail will be applied to the final CoSMoS 3.0 data release in the months to come, an initial analysis has been done overlaying the preliminary data with SDG&E assets. From this analysis, we receive an early indication of the linear footage of electric assets potentially impacted by sea level rise, as well as the number of overhead and underground transmission and distribution facilities (Table 16 and Table 17 below). While these results will be refined with the final CoSMoS 3.0 data release, the early numbers will allow planning of adaptation strategies to begin.

Table 16. Linear footage of electric assets potentially impacted by sea level rise

	Linear Feet of Electric Assets			
SLR (cm)	Duct Bank	Pole Line	Grand Total	Percent Impacted
0	647	366	1,013	< 0.01%
50	269,561	112,448	382,009	0.28%
100	556,190	204,511	760,701	0.55%
150	812,193	284,054	1,096,247	0.80%
200	1,206,658	400,165	1,606,823	1.17%

*All data are preliminary and produced for demonstration purposes only.

Table 17. Number of overhead and underground transmission and distribution assets potentially impacted by sea level rise

	Number of Point Electric Assets										
SLR (cm)	Distribution OH Structure	Dynamic Protective Device	Fuse	Substation	Surface Structure	Switch	Transformer Device	Transmission OH Structure	Underground Structure	Grand Total	Percent Impacted
0	N/A	N/A	N/A	N/A	1	N/A	1	N/A	2	4	< 0.01%
50	720	20	90	4	334	59	461	82	729	2,499	0.31%
100	1,291	37	194	13	713	199	920	173	1,387	4,927	0.62%
150	1,754	67	321	13	1,061	338	1,311	239	1,850	6,954	0.87%
200	2,555	113	540	17	1,628	529	1,981	383	2,584	10,330	1.30%

*All data are preliminary and produced for demonstration purposes only.

4. Adaptation Measures

In general, utilities can address climate vulnerabilities to their assets, operations, and systems (implement adaptation measures) through: 1) hardening of existing assets; 2) new construction and relocation; 3) policy, planning, and operations; 4) ecosystem-based measures; and 5) risk transfer. Implementing a portfolio of adaptation measures (including a combined set of different types to exploit beneficial synergies) can help to address the vulnerabilities and avoid the potential direct and indirect costs from hazards (DOE 2010, DOE 2016, GAO 2014).

In California, while utilities have disclosed strategic-level adaptation measures, the research did not find asset-specific adaptation measures for California utilities. The strategic-level adaptation measures consist of broad descriptions of approaches for managing risks to different asset for energy generation and distribution; emergency management planning; coordination with first responders and emergency officials; and planning and analysis measures.

The vulnerability assessment conducted by Con Edison provided detailed information on actions needed to enhance system resiliency (including assets, operations, and management practices). For example, the first phase of Edison storm-hardening projects sought to, among other measures, mitigate the infiltration of water in generating stations through pipes and conduits entering the station from the exterior (Figure 38).

Figure 38. Expansive foam seal used as a storm hardening response to the impacts of Super Storm Sandy (Con Edison, 2013)

Specifically, Con Edison infrastructure is built to FEMA flood levels plus 3 feet. PSE&G uses the New Jersey Department of Environmental Protection (NJDEP) flood hazard area rules based on FEMA post-Superstorm Sandy flood elevations; PSE&G assets are built to FEMA flood levels plus 1 foot.

Adaptation measures were also found in storm hardening plans focused on the East and Gulf Coasts; several utilities from the states of New York, New Jersey, Maryland, Arkansas, Louisiana, Mississippi, and Texas have filed for storm hardening funding in order to increase energy infrastructure resilience. Con Edison and National Grid of New York during and post Superstorm Sandy also employed operational changes to build resilience. As Superstorm Sandy approached, the two utilities isolated some low-lying parts of their networks to ensure that the impact of the intrusion of water would be limited, rather than spreading system-wide.

During the interviews with utility representatives, it was noted that the most significant barrier to the identification and implementation of adaptation measures is the lack of regulatory approval for rate increases. Utilities have submitted rate case proposals requesting funding for climate and extreme weather adaptation efforts; however, regulators did not approve the full amount as they determined that the utility failed to meet the burden of proof to justify the requested rate. Utilities indicated that the discrepancy between the amount of funding that utilities request and the amount that regulators deem reasonable is due to lack of sufficient guidance from regulators. Specifically, utilities cited a lack of guidance and standardized practices regarding climate scenarios, methods for evaluating vulnerability and the discrimination between climate-induced versus existing vulnerability, as a cause for the disagreement over the magnitude of climate impacts and consequent adaptation needs. One utility noted public perception and the political climate also impacts regulatory approval, and that it is critical to request funding within the policy "window of opportunity," or soon after a significant climate event has occurred and lead to service outages.

E. Conclusion

Below is a summary of the significant findings from this literature review and discussion of implications for the tasks that the team will undertake next.

Coastal Hazards

1. The preliminary CoSMoS 3.0 coastal hazard model includes the necessary SLR-related processes (i.e., SLR, wave run-up, and coastal erosion) and its results are appropriate to provide a preliminary coastal hazard overlay for SDG&E assets. The ICF team may use the preliminary information to test geospatial analysis techniques at the outset of Task 3, which will promote rapid integration of the final CoSMoS 3.0 model results once they are available.
2. Under Task 3, the ICF team will take several actions to ensure the best available science is appropriately applied for the SDG&E service territory:
    a) Interpret results from Scripps Institution of Oceanography's probabilistic regional SLR scenarios to compare against final CoSMoS 3.0 model results.
    b) Validate the results from final CoSMoS 3.0 model against the SPAWAR model results, FEMA FIRM, previously described NRC projections, and maps of previous SLR assessments to ensure the applicability of the results in the San Diego coastal region.
    c) Verify existing coastal flood and erosion mitigation infrastructure (e.g., sea walls, berms) through remote and land-based surveys to confirm the quality of data included within final CoSMoS 3.0 model results.
    d) Interpret final CoSMoS 3.0 results to align with key planning time periods (e.g., 2030 and 2050) and SLR scenarios provided by the CEC.

Assets and Operations

3. The research uncovered information on general climate-related hazard sensitivity thresholds for electric assets, but the level of detail is not sufficient to inform asset-specific analysis. Therefore, further work will be done under Task 3 with SDG&E subject matter experts to better understand the sensitivity of specific SDG&E key (critical) assets.
4. The literature review did not provide sufficient information to determine critical, priority electric assets within the SDG&E system; many of the documents reviewed lacked asset-specific focus. Additional work with SDG&E subject matter experts will be conducted under Task 3 to analyze the criticality of assets and operations to the system function.

Adaptation Measures

5. There is a significant amount of information on general risk mitigation strategies, methods, and best practices that utilities have undertaken or plan to undertake from a business risk perspective that should be leveraged to identify adaptation measures. The applicability of these general risk management approaches will be further explored with SDG&E subject matter experts in subsequent tasks.

6. To build upon the general climate adaptation measures identified through the literature review, additional work under Task 6 will need to be done with SDG&E subject matter experts to help guide the development of potential adaptation measures relevant to the SDG&E context.

Additional Resilience Measures

I. SDG&E Microgrid

In 2008, SDG&E received an $8 million grant from the U.S. Department of Energy to help launch the development of a microgrid in Borrego Springs, a remote area in the deserts of eastern San Diego County that has historically experienced power outages due to the extreme local weather conditions. In 2015, the California Energy Commission awarded SDG&E a nearly $5 million grant to expand the innovative Borrego Springs Microgrid. The grant allowed for a connection between the Microgrid and the nearby 26-megawatt (MW) Borrego Solar facility to power the community, making the project one of the nation's largest microgrids that can operate solely on renewable energy. In addition to bringing in more clean power, the funding has been used to increase the size of the Microgrid to service all of Borrego Springs, a community with 2,800 customers, further enhancing local reliability and reducing the duration of power outages.

The Borrego Springs Microgrid uses advanced technologies – including local power generation, energy storage, and automated switching – to create a more resilient local grid. The Microgrid is connected to the centralized energy grid, but can disconnect from the larger grid and function independently during emergencies, supplying vital electricity to the local community through its online resources. The Microgrid has already kept electricity flowing to the community during several power outages, demonstrating its potential to benefit all customers.

SDG&E has connected the Microgrid to NRG Energy's 26-megawatt Borrego Solar facility, using this clean energy to power the entire town during the day. The challenge is that renewable energy is intermittent by nature and requires back-up resources when solar becomes unavailable, such as at night or when a cloud moves in front of the sun. The Microgrid's large batteries account for this intermittency in supply and smoothly integrate renewable resources onto the local grid. The batteries also store the abundant solar power generated during the day for use at night, when solar is unavailable and the Microgrid powers the most critical loads in the community, such as cool zones, gas stations and grocery stores. If the batteries exhaust all their power, the system accesses traditional onsite generation. SDG&E uses computer software to make sure all these transitions happen seamlessly and maintain a consistent flow of power to the community.

As it has become more sustainable the Microgrid has also grown in scope. SDG&E expanded the size of the Microgrid from serving approximately 1,000 customers to incorporating all 2,800 metered customers who live in Borrego Springs. If a large outage were to impact the whole town, the Microgrid can switch from running in parallel with the main grid, to "islanding" mode, when the Microgrid runs on its onsite generation resources. This means that the Microgrid can keep electricity flowing during an emergency or other grid disturbance, enhancing reliability for the whole community. The town would also be running on locally-sourced renewable energy, making the system greener and more sustainable overall.

In late May of 2015, the Borrego Springs Microgrid was used to power the entire community of Borrego Springs during planned grid maintenance, thus avoiding major service interruptions to customers. SDG&E employed the Borrego Springs Microgrid because the transmission line that usually feeds the community had been damaged by lightning. SDG&E crews needed to replace or repair three transmission poles, which would usually require a 10-hour sustained outage to the entire community of Borrego Springs. However, SDG&E was able to call on the Borrego Springs Microgrid to avoid the impact of a major outage.

SDG&E seamlessly switched over to the Microgrid to power the entire community at 8:45 a.m. on May 21, allowing the maintenance work to begin. The Microgrid generated the majority of power during this time from NRG Energy's large Borrego Solar facility, using batteries and traditional distributed generation to "follow the load" and fill in gaps created by the solar facility. This was necessary because of the intermittency of solar power in nature due to clouds moving in front of the sun. The Microgrid uses advanced computer software and automated switching to ensure the fluctuations were accounted for in real time. This innovative network of resources working together to support each other kept a steady supply of power flowing to Borrego Springs throughout the day. At 5:30 p.m., SDG&E completed the grid maintenance and switched the town back to the main grid. Rather than having an extended, 9-

hour outage, customers experienced a planned outage of less than 10 minutes as they were switched back from the Microgrid to the repaired transmission feed.

Figure 39. The SDG&E Borrego Springs Microgrid.

II. SDG&E Outage Prediction Model

In anticipation for a continuation and possible increase in the occurrences of significant extreme weather events impacting its service territory, San Diego Gas & Electric and Atmospheric Data Solutions have developed a state-of-the-art outage prediction model. This forecast model is taking an ensemble approach by leveraging multiple techniques to correlate an extensive database of historical weather data, high resolution weather forecast model output, and historical outage data, creating a 96-hour forecast that predicts the number of outages expected on the system and the total number of customers that could be impacted. This forecast is parsed into the eight operating districts across SDG&E.

The first technique that is being used is a machine learning methodology leveraging an Artificial Neural Network (ANN) referred to as Self Organizing Maps (SOM). SOMs use pattern recognition to look at an overview of atmospheric conditions such as the strength of the jet stream, atmospheric moisture, barometric pressure, and wind speeds above the surface and compare it to historical occurrences using spatial correlations and Euclidean Distance Analysis.

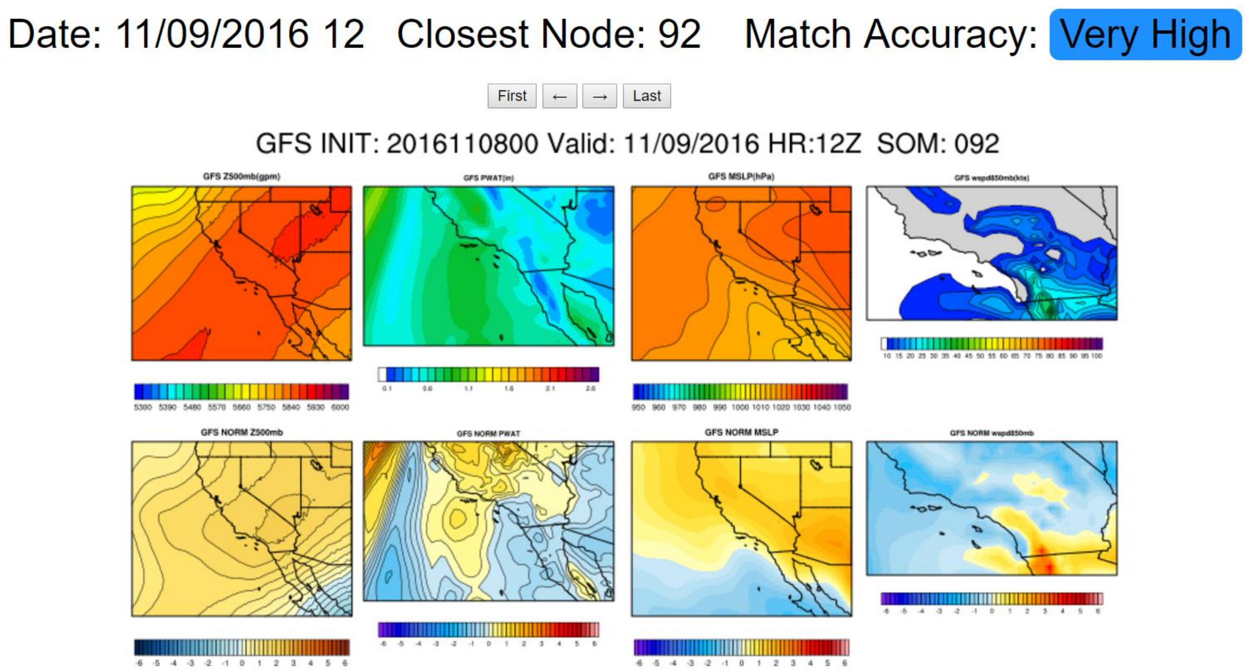
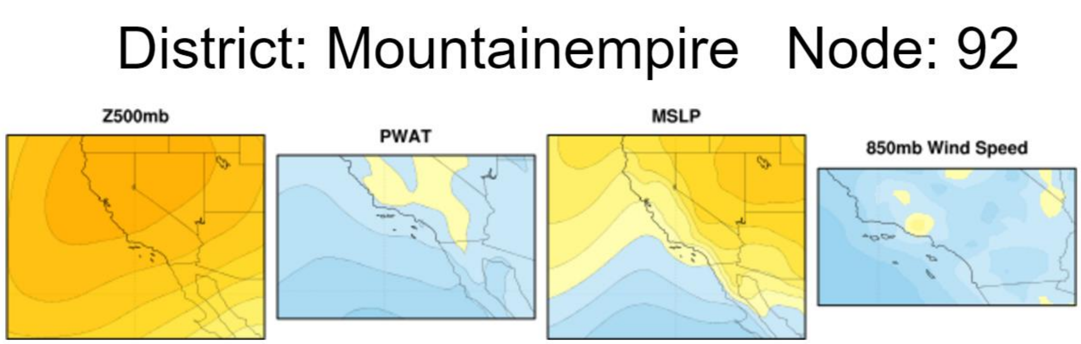


Figure 40. Example of SOM output generated by the outage prediction model developed by Atmospheric Data Solutions.

When the nearest "match" to the current scenario is identified, the forecast model then references a detailed outage database and extracts all weather related outages that have been experienced under similar conditions. This forecast is then broken up into the eight operating districts across the SDG&E service territory providing the outage counts, customer impacts, wind speed and temperatures from similar storms in the past.



Outages Associated with this Node

Date (UTC)	Outage Count	Customer Impact
2006-06-24 12:00:00	3	1567
2006-07-16 00:00:00	5	155
2010-11-03 12:00:00	1	10
2014-11-06 00:00:00	1	73

Figure 41. Example of district outage database generated by the outage prediction model developed by Atmospheric Data Solutions.

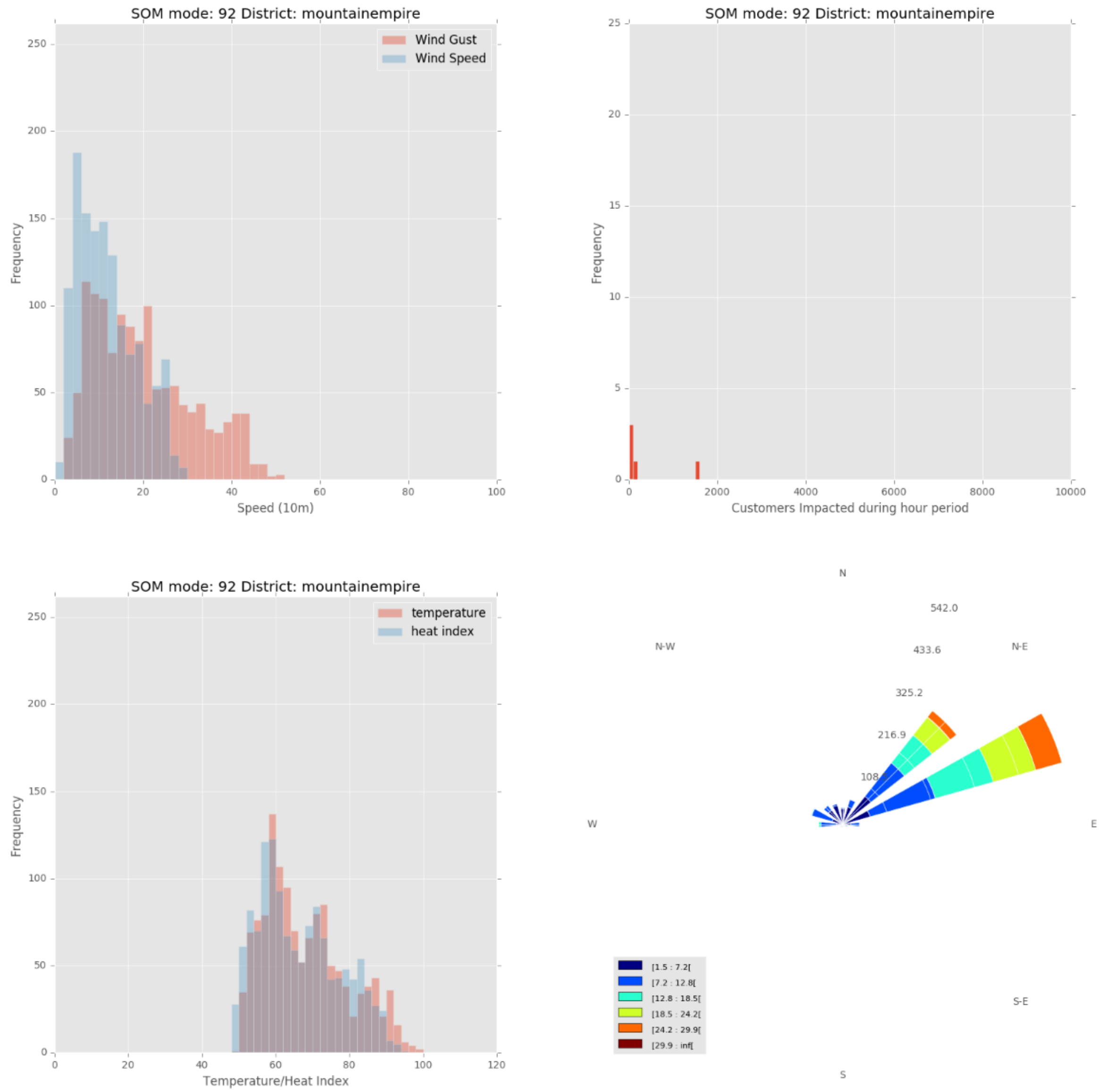


Figure 42. Storm statistics based on similar historical events from the outage prediction model developed by Atmospheric Data Solutions.

When the SOM forecast explained above indicates that certain districts in the SDG&E service territory are will be prone to outages, a more detailed model will be run through a partnership with Chapman University. This secondary model is being developed to forecast power outages and customer impacts for the eight SDG&E operating districts. Leveraging close to 1MM compute core hours of high-performance computing, the Weather Research & Forecasting (WRF) model was used to hind cast and forecast the weather at a resolution of 2 kilometers. In addition, lightning data is also forecasted based on the observed data provided by SDG&E and WRF. These two modeled data outputs are feed into two different machine learning models to forecast power outages.

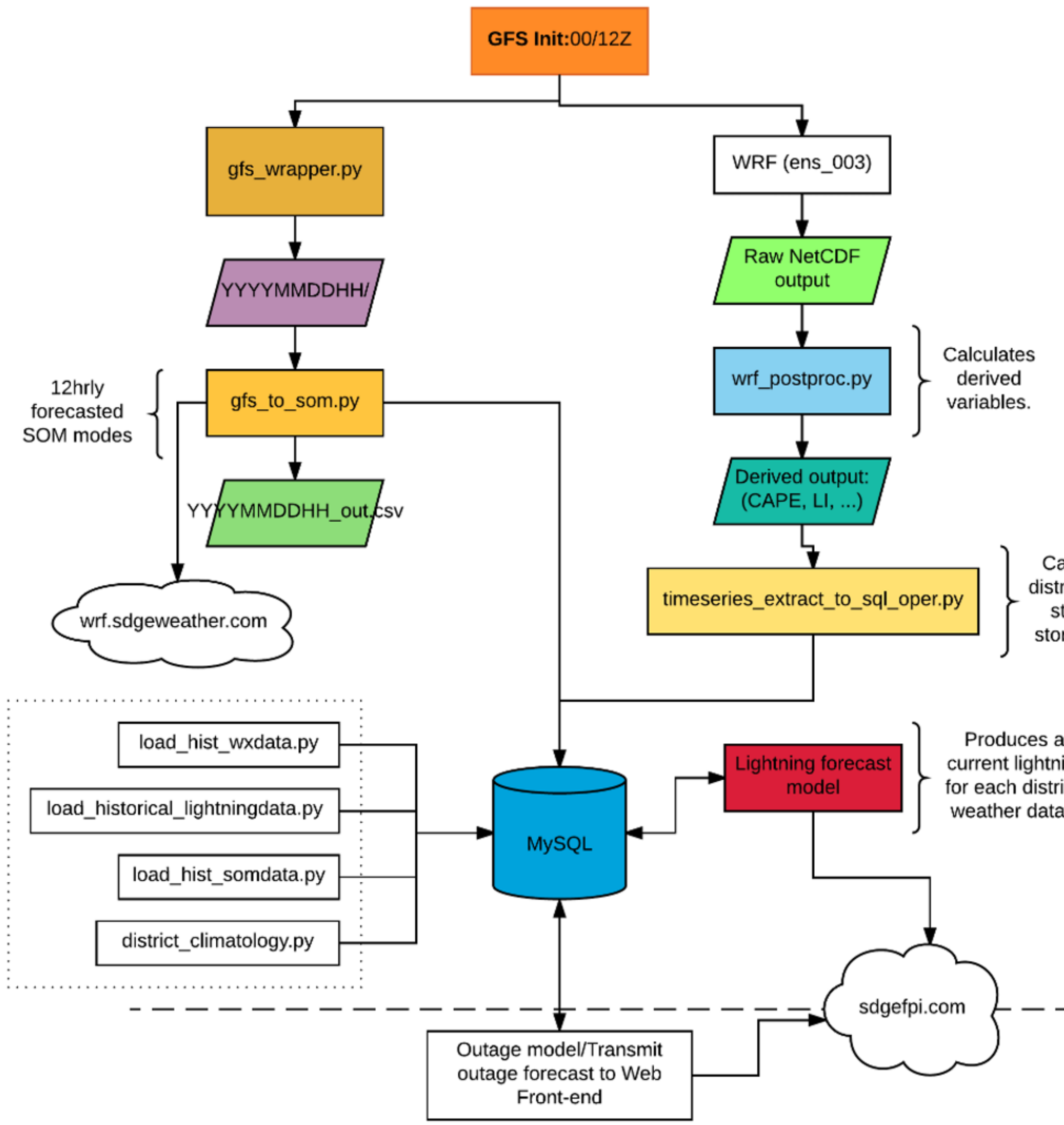


Figure 43. Flowchart of processes for SOM-based outage prediction model (left branch) and ARIMA model (right branch) developed by Atmospheric Data Solutions and Chapman University.

In the data processing step, the four-terabyte WRF dataset is summed, averaged, maximized, and minimized in a moving three-hour window to have an enhanced accuracy in forecasting. At this point, seasonality and trend are removed and the residual is the only remaining dataset analyzed. This dataset shows the true variation of anomalies and departures from standard climatic conditions. The residual dataset is fitted to an Autoregressive Integrated Moving Average (ARIMA) model. This model, at a 99% confidence interval, can detect any extreme anomalies that occur over the span of the dataset, indicate to SDG&E when extreme events have occurred in the past, and develop means of predicting them in the future. The noted timestamps of extreme events from the ARIMA 99% confidence interval analysis are then coupled with the WRF and lightning dataset to develop a Generalized Linear Model (GLM) to isolate the positive predictors (weather variables that are significantly associated with power outages). After these positive predictors are identified, a model is built to forecast a binary case of power outages (yes or no power outage), number of power outages, and number of customers impacted.

Moreover, SDG&E has simultaneously made significant headway into developing a tangential operational outage prediction system, leveraging Artificial Neural Networks (ANN) to create an ensemble forecasting system, increasing forecast confidence. Through this effort, a system of automated training techniques of varying topological properties has been developed. These techniques are being applied to train on historical weather and outage data to create models to forecast upcoming conditions and outages. Weather data is given to the model after being pre-processed through Principal Component Analysis (PCA) and other feature selection and data reduction methods, and the model is trained to forecast outage statistics based on this processed input.

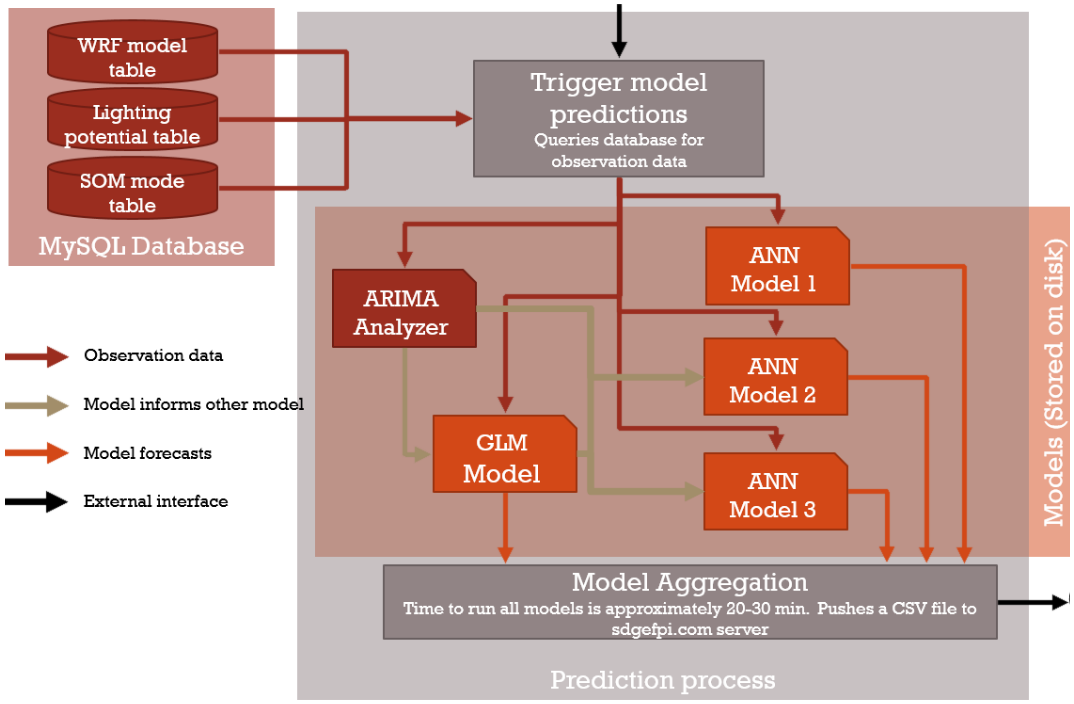


Figure 44. Flowchart of the ensemble forecasting system.

Currently, the different models and approaches consistently converge quickly onto ideal parameters and are able to predict outage statistics within historical data sets with high strength and accuracy. Progress continues, and validation rises as more meaningful predictors are introduced (including lightning data and SOM mode information described above) and more state-of-the-art techniques and methods are employed, including neural network configurations and machine-learning-friendly data pre-processing techniques.

SDG&E Meteorology is the recipient of the outage prediction model information and, after the data has been validated, the information is converted into a three-level index known as the Outage Potential Index (OPI). The OPI rates each 12-hour period for the next 96 hours as either Normal, Elevated, or Extreme based upon the potential for damage on the system. Data is then integrated into SDG&E Meteorology's Weather Awareness System for communication with our SDG&E System Operators and Management

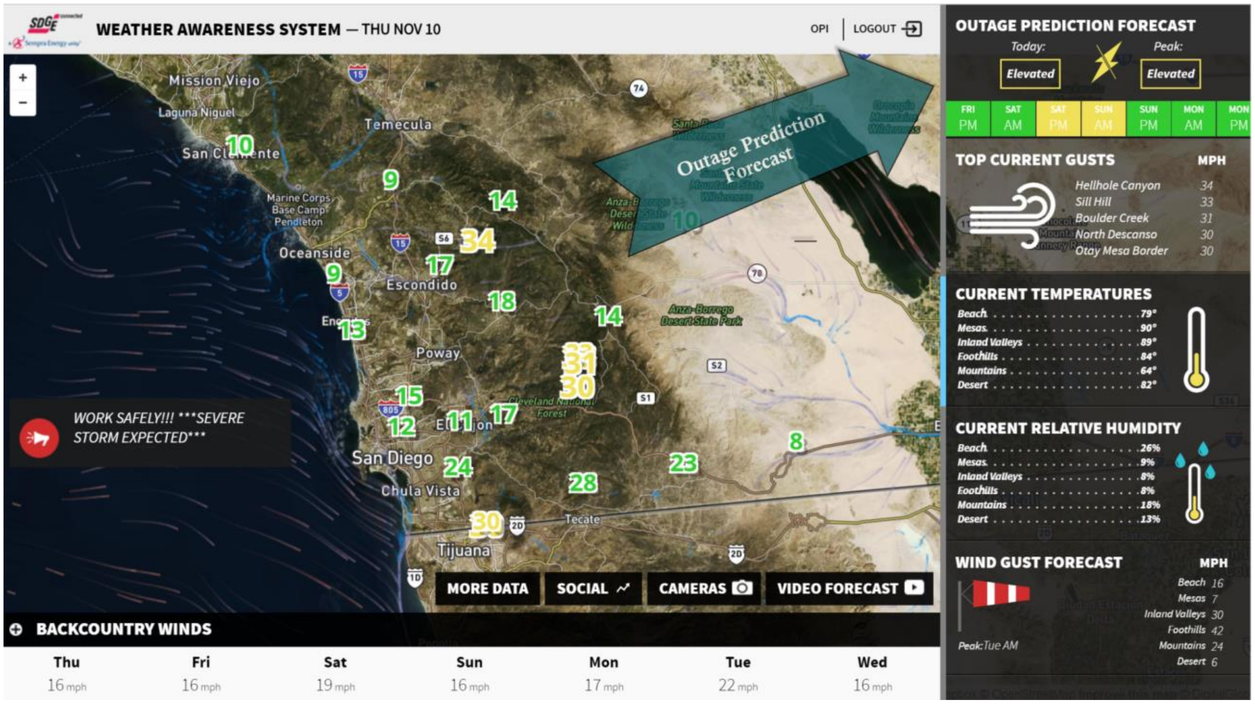


Figure 45. Outage Prediction Index as displayed on the SDG&E Meteorology Weather Awareness System.

III. Department of Homeland Security Hurricane Scenario Analysis

The San Diego Gas & Electric (SDG&E) Emergency Management department is working with the Office of Cyber Infrastructure and Analysis (OCIA), in coordination with the National Infrastructure Simulation and Analysis Center (NISAC), to conduct a hurricane analysis for the San Diego, CA, region. The analysis will assess the potential impacts to the 16 critical infrastructure sectors (including identifying gas and electric vulnerabilities), the population, and the economy resulting from a hypothetical Category I hurricane. SDG&E has initiated work with Los Alamos National Laboratory to incorporate gas and electric infrastructure into this report.

The Hurricane Scenario Analysis contributes to the Nation's preparedness from catastrophic hurricane landfall with modeling tools that examine critical infrastructure dependencies, interdependencies, and potential cascading impacts to produce consequence estimates for use by Federal, State, and local stakeholders. For the San Diego region, a landfalling hurricane would be a representation of projected climate threats, including, but not limited to, extreme temperatures and humidity, coastal storm surge, and inland flooding. To assist in the analysis process, SDG&E will be collaborating with OCIA-NISAC to identify the potential impacts resulting from a disruption to critical infrastructure.

The most current information provides OCIA-NISAC with the accuracy needed to provide useful modeling and analysis to Federal, State, local, and private sector stakeholders. Analysis results, again, based on stakeholder input, will demonstrate likely impacts to SDG&E, including:

- Tropical heat wave impacts on electric system load;
- Inland flooding impacts on electric infrastructure; and
- Landslide and mudslide impacts on electric infrastructure.

In addition, analysis results may provide valuable insight into Federal, State and local planning activities, such as:

- Government continuity operations planning;

- Supply pre-positioning;
- Prioritizing of response and recovery operations; and
- Evacuation planning.

The proposed report will include a literature review, an SDG&E infrastructure threat assessment of direct effects from a potential hurricane, and State and local input for scenario generation and hurricane category determination.

Resilience Plan for Gas Infrastructure

I. Regional Climate Impacts and Adaptation Studies for Natural Gas Systems and Other Environmental Related Issues

A. Introduction

In addition to the project introduced under the chapter titled *Resilience Plan for Sea Level Rise,* San Diego Gas & Electric (SDG&E) is collaborating with ICF International to investigate the impacts of climate change on the natural gas system. This grant project, also funded by the California Energy Commission, seeks to establish a better understanding of vulnerabilities and adaptation measures so that appropriate policy and planning decisions can be made to ensure future reliability, while minimizing costs to customers. Through this project, detailed impact assessment analyses that build on previous studies are used to identify the SDG&E gas infrastructure that will be exposed to coastal and inland climate hazards, including sea level rise, inland flooding, landslides, and wildfire, and assess how the gas system could be affected.

To convey work efforts, the sections to follow are structured into four sections: 1) **Purpose**- *what was the reason for the task*; 2) **Methodology**- *what was the plan to complete the task*; 3) **Research**- *what did we find*; and, 4) **Conclusion**- *what does this mean moving forward*. To better align with the Technical Approach in the ICF proposal, the Research Section is divided into four parts: 1) Review existing coastal hazards efforts, including **sea level rise (SLR)**; 2) Review existing **inland hazard** efforts; 3) Develop knowledge of sensitivity of **assets and operations**; and, 4) Identify recommended and/or considered **adaptation measures**.

B. Purpose

Although this project is focused on the SDG&E natural gas service territory, the purpose of the following sections is to conduct a comprehensive review of widespread material and information to ensure that the project builds on the latest research regarding natural gas sector vulnerability to select coastal and inland hazards in an effort to identify potential adaptation measures. In doing so, gaps in the current state of knowledge of natural gas sector vulnerability to coastal and inland climate hazards will also be uncovered. By identifying the vulnerabilities and physical processes causing those vulnerabilities, practical, decision-focused analysis can be conducted at a level of detail appropriate for informing planning, program, and policy decisions. It can also aid in the identification of SDG&E-specific adaptation measures and strategies.

C. Methodology

ICF implemented a multifaceted approach to ensure that the review of material and information was comprehensive and germane to the scope of the project. The first step was to establish a list of "*key words*" and "*key phrases.*" With this list of "*key words*" and "*key phrases,*" ICF conducted a literature search using the Elton B Stephens Company (EBSCO) Host Research Databases, the California Natural Resources Agency "*Planning for Sea Level Rise*" database (AB2516, Gordon), and general internet searches using Google and other search engines. The EBSCO Host Research Databases provided ICF with a list of relevant worldwide published documents, reports, and studies, while ICF used the *Planning for Sea Level Rise* database to identify California-specific studies, assessments, and programs aimed at addressing sea level rise. General searches on the internet provided ICF with a list of published and unpublished documents, reports, and studies, and links to relevant projects, presentations, and articles.

This effort was supplemented by coordinating with our Technical Advisory Committee (TAC) group made up of climate change experts and Stakeholder Group comprised of California utilities and regional/local government representatives. At the start of the effort, ICF held a meeting with the TAC and Stakeholder groups to introduce group members to the project and solicit their feedback on the project and task approach. Another benefit of the meeting was to request them to identify (and if possible provide) essential material (i.e., documents, reports, and studies) they believe should be considered as part of this project. The group members were not all centrally located, since ICF saw value in convening diverse TAC and Stakeholder Groups that could provide insight into the current best-practices in climate change adaptation. Due to logistical complications, competing priorities, and budgetary constraints, it was determined best to conduct meetings via conference call where ideas and material could be exchanged and shared, instead of in-person meetings.

Members of the ICF team also provided relevant material, drawing from: 1) current and past efforts, 2) other meetings and conferences, and 3) general experience in the subject areas. An example of this is the leveraging of recently produced climate-related studies by utility companies. As part of the requirement under the U.S. Department of Energy (DOE) Partnership for Energy Sector Climate Resilience,[22] partnering utility companies were requested to submit vulnerability assessments. The ICF team reached out to a variety of utility companies to obtain copies of their DOE-requested Vulnerability assessments. While our contact with some of the utility companies was focused on obtaining the DOE vulnerability assessments, we also inquired about other material that might be of use for the project and our efforts (i.e., regulatory filings, design standards).

The ICF team augmented the literature research with expert interviews. The interviews were used for three purposes: 1) to validate findings, 2) to fill knowledge gaps, and 3) to understand concurrent 4th Climate Change Assessment efforts. Information learned from the interview process is included in the relevant research sections: 1) Existing coastal hazards efforts, including **sea level rise (SLR)**; 2) Existing **inland hazard** efforts; 3) Knowledge of sensitivity of **assets and operations**; and 4) Recommended and/or considered **adaptation measures**. The ICF team met with various climate change experts and representatives from Natural Gas utility companies (both in California and across the country) to get a better sense of key, relevant efforts and available information. To serve as an aide during the interviews and promote consistency, the ICF team developed a list of questions to help gain a better understanding of how climate change vulnerability was being addressed (Appendix D). The ICF team also met with Project Managers working on projects under the 4th Climate Change Assessment. Through the CEC and the Natural Resources Agency (NRA), ICF attended several workshops, conference calls, and follow up meetings with Project Managers from various CEC and NRA 4th Climate Change Assessment projects.

D. Research

The goal at the outset of our research effort was to establish a solid understanding of the work being done on climate change broadly and SLR and inland climate-related hazards in particular, with a focus on what's being done in the San Diego area. The ICF team initially searched for assessments that had been undertaken at a state-wide level (e.g., the Pacific Institute (2009) analysis of the potential impacts SLR to the coast of California) and then refined the analysis specifically to those studies that have assessed impacts within SDG&E's service territory. The research uncovered a range of material from assessments to strategic plans to guidance documents. Each of these provided additional insight into the considerations, influences, and factors of coastal and inland climate-related hazards.

Below is a summary of the more relevant completed climate change and/or SLR assessments or plans specific to the San Diego region reviewed by the ICF team:

- *SLR Adaptation Strategy for San Diego Bay,* International Council for Local Environmental Initiative (ICLEI): a regional, collaborative, stakeholder process undertaken as part of the San Diego Regional Climate Protection Initiative, a partnership with the San Diego Foundation and all local governments in the San Diego region, which consists of a vulnerability assessment that evaluates how community assets could be impacted by SLR, as well as recommendations for building the resilience of those community assets.
- The City of Chula Vista completed a high-level vulnerability assessment in 2010 and adopted *Climate Adaptation Plan Strategies* in 2011 (City of Chula Vista, 2011). The outcomes of the study informed the City's involvement in the ICLEI study (above).

[22] http://energy.gov/epsa/partnership-energy-sector-climate-resilience

- *Climate Action Strategy*, The San Diego Association of Governments (SANDAG): a climate action strategy to identify land use and transportation policy measures that could help SANDAG meet or exceed its Senate Bill 375 (Steinberg, Chapter 728, Statutes of 2008) targets for reducing Greenhouse Gases (GHG) from passenger cars and light-duty trucks.
- *Regional Focus 2050 Study,* The San Diego Foundation: explores what the San Diego region will be like in the year 2050 if current climate trends continue, based on projections of climate change generated by scientists at Scripps Institution of Oceanography (SIO).
- *San Diego, 2050 is Calling,* Climate Education Partners (CEP): part of an effort to develop and implement a climate change education plan for the San Diego region, this report identifies key climate hazards and the implications of their potential impacts in the San Diego area.
- *A methodology for assessing the impact of sea level rise on representative military installations in the Southwestern United States,* The Space and Naval War Systems Command (SPAWAR): a SLR and coastal hazard vulnerability study focused on the Pendleton Marine Corp Base and Coronado Naval Base (Chadwick, 2014). The study utilizes a series of models to evaluate long term shoreline seasonal beach changes, and used the results of change models to iteratively project the extent of future coastal flood, erosion, and tidal inundation.
- *Draft Fee Study for Shoreline Protective Devices,* The City of Solana Beach (2015): aims to (a) establish a methodology to quantify beach value and determine an impact mitigation fee to compensate the public for recreational loss associated with the installation of shoreline protective devices, and (b) provide an analysis of potential offsets to this fee, such as public safety benefits. The study includes sea level rise projections through 2050 along with an analysis of the projected impacts of sea level rise impacts on bluff erosion.
- The *Integrated Feasibility Report and Environmental Impact Statement/Report (EIS/EIR)* for the *Encinitas-Solana Beach Coastal Storm Damage Reduction Project* prepared to identify and evaluation potential environmental impacts incurred from the proposal project. Sea level rise scenarios for the Encinitas and Solana Beach areas were used to establish the requirements for various protection measures to mitigate coastal erosion-induced storm damage between 2018 and 2068.

In addition to the above, the ICF team reviewed a number of vulnerability assessments and planning processes underway throughout the region. Below is a summary of the more relevant work:

- The City of Imperial Beach is conducting a vulnerability assessment, economic analysis, and adaptation planning (Revell Coastal, 2016) focused on vulnerability to coastal flooding, nuisance flooding, and tidal inundation based on the climate-related variables of sea level, wave height, and extreme tides. Adaptation planning includes an examination of a suite of potential alternatives including managed retreat, armoring, nourishment, living shorelines, and groins using a holistic cost benefit analysis and modeling of physical response to the proposed adaptation strategies.
- The City of Del Mar is in the process of developing a coastal hazard vulnerability and risk assessment, and has released a draft document. The assessment focuses on vulnerability to coastal flooding, bluff erosion, and river flooding, and is based on climate-related variables of sea level, wave height, precipitation and river flow (ESA, 2016). A combination of observed impacts from historic extreme events and projections for future extreme events are being used to evaluate vulnerability (ESA, 2016). The City is currently in the process of developing and selecting adaptation options.
- The City of Carlsbad is in the process of developing a coastal hazard vulnerability and risk assessment. The assessment focuses on vulnerability to coastal flooding, bluff erosion, and river flooding, and is based on the climate variables of sea level, wave height, precipitation and river flow available from CoSMoS 3.0. This also includes analysis of storm drain systems and the three lagoons within the City of Carlsbad. This report is expected to be released in September 2016.

- The San Diego Climate Collaborative received a NOAA Coastal Resiliency Grant. This grant funded project includes a county-wide vulnerability assessment to be completed by ICLEI, and a San Diego River coastal confluence modeling study to be completed by Revell Coastal. Expected grant completion is March 2017.

ICF also reviewed a select number of energy utility vulnerability assessments, addressing either projected climate impacts, existing extreme weather hazards, or both. While the review focused on assessments from major California energy utilities (i.e., Pacific Gas and Electric- *PG&E*, Southern California Edison- *SCE*, Sacramental Municipal Utility District- *SMUD*, and SDG&E), it also included a selected number of vulnerability assessments from utilities outside of California, including Consolidated Edison (Con Edison) and Seattle City Light. The review discovered varying degrees of analysis with most discussing vulnerability at the larger system level. The documents also used a variety of SLR and climate hazard scenarios.

The ICF team also held a series of conference calls with representatives from a variety of natural gas utility companies. The purpose of the meetings was to provide further insight in their climate change efforts and in particular their recent work on climate change vulnerability assessments, including the identification of key assets and operations. The calls uncovered the types of climate change hazards they research, the scenarios/drivers used, challenges faced in completing the work, and next steps. The ICF team spoke with representatives from Public Service Electric and Gas (PSE&G), SCE, SMUD, PG&E, and Con Edison.

Follow up meetings were also conducted with select members from the TAC Group, the San Diego Regional Climate Collaborative (Laura Engeman), and the San Diego Foundation (Nicola Hedge), to gain a broader perspective on work being done in the San Diego region. The meetings provided greater awareness of the data currently being used, challenges in leveraging and incorporating the data, limitations of the data, and missing data.

The following sections provide a summary of the focused research areas.

1. Coastal Hazards

Research under this subtask focused on understanding:

- projections of sea level rise for California and the local San Diego area; and
- key issues of changes to coastal processes.

The research also led the ICF team to identify available information on coastal hazard models.

Sea Level Rise

The National Research Council (NRC) of the National Academies (2012) summarize the state of the science SLR scenarios for Washington, Oregon, and California. The study identified suitable regional projections based on the best available science available at the time. Table 18 provides a summary of the NRC SLR ranges (the possible but unlikely upper and lower bound) and projections (the most likely value) for the area of California south of Cape Mendocino (City and County of San Francisco 2015).

In 2015, the California Coastal Commission (CCC) released a policy guidance document, *Sea Level Rise Policy Guidance: Interpretive Guideline for Addressing Sea Level Rise in Local Coastal Programs and Coastal Development Permits* (CCC 2015), which lays out their expectations for incorporating SLR into Local Coastal Program updates and coastal development permits. The document recommends the use of the NRC 2012 SLR scenario ranges (see Table 18).

Table 18. Regional SLR Ranges and Projections for California south of Cape Mendocino (NRC 2012)

Time Period*	SLR Range (B1-A1FI scenario)	Projection: Los Angeles, CA (A1B scenario)
By 2030	2 – 12 in (4 – 30 cm)	6 ± 2 in (15 ± 5 cm)
By 2050	5 – 24 in (12-61 cm)	11 ± 4 in (29 ± 9 cm)
By 2100	11 – 66 in (42 – 167 cm)	37 ± 10 in (93 ± 25 cm)

*relative to the year 2000

The ICF team interviewed Dr. Dan Cayan from Scripps Institute of Oceanography to discuss available SLR data and scenarios. Dr. Cayan is leading a CEC-funded 4th Climate Change Assessment grant project to develop probabilistic regional SLR scenarios. Dr. Cayan recommended that the project team use these data, when released, as the basis for the sea-level rise exposure analysis. Dr. Cayan based this recommendation on the fact they the new data will make use of the latest understanding of the specific inputs into the sea-level rise scenarios, including ice sheet-melt dynamics. The California Energy Commission is utilizing Dr. Cayan's work to help defining common SLR recommendations. These recommendations will be considered once available.

Coastal Processes

Coastal Erosion

Research indicates that cliff erosion in San Diego is driven primarily by coastal processes (e.g., wave run-up and tides) and precipitation (Young and Ashford 2006). Gullying during rain events can cause substantive erosion of the cliffs and add significant volumes of sand to the littoral system. Additional research indicates high wave energy seasons would cause excessive erosion above average while reduced wave energy conditions would result in a wider beach and more seaward shoreline location. Such changes to the coastline can have significant effects on the extent and depth of temporary and permanent inundation associated with SLR and storm events (Yates et al. 2009).

Wave Run-up

Wave run-up is the maximum vertical extent of wave uprush on a beach or structure above the still water level (Sorensen, 1997). Recent research suggests that dynamic wave run-up calculations, including the time varying run-up (e.g., calculations included within the Xbeach and Eurotop models), performed better than empirical total water level calculations (i.e., wave overtopping and flood extent mapping). Other material on this topic calibrated a total water level run-up equation based on observed measured wave run-up elevations from research around the country (Stockdon, Holman, Howd, and Sallenger 2006). Wave height increases can magnify the impact of SLR, increasing the extent of coastal inundation, erosion, and associated Natural Gas asset exposure.

Tidal Inundation

Tidal flooding—coastal flooding that occurs during tidal conditions not associated with coastal storms or heavy rainfall—can overwhelm storm drains, cause road closures, and deteriorate infrastructure (National Oceanic and Atmospheric Administration-NOAA 2014). Gradual local SLR, particularly if combined with the loss of natural coastal barriers, may increase the frequency and/or the extent of impacts for tidal or continuous flooding, which may introduce new risks to natural gas service and assets (NOAA 2014). For some locations, "king tides" (the highest predicted high tide of the year at a coastal location) may provide an example of conditions that will occur more frequently in the future because of SLR.

Coastal Hazard Models

The Coastal Storm Modeling System (CoSMoS) is a multi-agency effort led by the United States Geological Survey (USGS) to make detailed projections (2 meter horizontal resolution) of coastal flooding and erosion based on existing and future climate scenarios for Southern California. The current version of modeling effort (v 3.0 preliminary release in November 2015) depicts coastal flooding, shoreline change, and potential cliff erosion response to a 100-year wave event in combination with various elevations of SLR and baseline water levels (i.e., high tide, storm surge, sea level anomaly and river discharge). The USGS has produced results from four SLR scenarios (i.e., 50 cm (0.5 m), 100 cm (1.0 m), 150 cm (1.5 m) and 200 cm (2.0 m). It is important to note that the preliminary CoSMoS 3.0 release includes a certain set of assumptions regarding the ongoing existing mitigation actions or projects (for example assuming that prior coastal nourishment efforts will continue in the future). The final CoSMoS 3.0 data will include scenarios that include different sets of assumptions. Therefore, the actual inundation and erosion results from the final CoSMoS 3.0 release could be higher in some areas and lower in others than the preliminary data.

The ICF team met with the USGS team to discuss the work being performed on CoSMoS 3.0. Revisions to CoSMoS 3.0 are expected in the early fall of 2016, and anticipated to include 40 scenarios based on 25 centimeter increments (between 0-2 m) and a 5 meter SLR scenario. In addition, it will combined SLR with storm return period scenarios (no storm, annual, 20 year, and 100 year storm scenarios). This will be a significant improvement to the preliminary data release. The USGS team also informed the ICF team that CoSMoS 3.0 is planned to provide better consideration and integration of concurrent processes (coastal erosion, wave run-up) to better estimate potential flooding impact.

The Federal Emergency Management Agency (FEMA) has also developed a flood (coastal flooding) Loss Estimation model called Hazus. The Hazus model is often used to estimate potential damage from coastal floods and is a practical tool for planning purposes. The Hazus model does not take into account climate change variables; however, the model is able to import hazard data that is reflective of climate change considerations. Similarly, the damage estimates are based on 2010 Census information but the model is able to import customized data sets that enable users to gain a greater understanding of more realistic impacts.

2. Inland Hazards

In accordance with the scope of the proposal and grant agreement, the ICF team researched, collected, and analyzed material on the following inland hazards: 1) inland flooding; 2) landslides and mudslides; 3) extreme heat; and, 4) wildfire. Consideration was given to subsidence brought on by drought; however, initial research determined that subsidence was not an issue in the San Diego region. This research covered current local practice of addressing inland hazards as well as current approaches to projecting climate change impacts on inland hazards. The research also led the ICF team to identify available information on inland hazard models.

The San Diego County Office of Emergency Services (OES) Hazard Mitigation Plan (HMP) provided excellent insight into current practices for addressing inland hazards; and its update, currently underway, will provide guidance on how the County is incorporating climate change considerations into its analysis. The ICF team's working experience developing HMPs will be leveraged to fill the gap until the updated San Diego County HMP is available. To the right is a summary of the relevant research.

Hazard Mitigation Plans (HMP)

The purpose of HMPs are to assess natural and man-made hazards within the community and identify actions to eliminate and/or reduce the impacts. Future HMPs are required to incorporate climate change considerations into its analysis

Inland Flooding

The San Diego County HMP describes a flood as the occurrence of excess water from snowmelt, rainfall, or storm surge that accumulates and overflows onto a river's bank or to adjacent floodplains. Several factors determine the severity of floods, including rainfall intensity and duration. A large amount of rainfall over a short time span can result in flash flood conditions.

San Diego County's HMP determined that floods are a significant hazard to the region for three primary reasons:

1) Much of San Diego County terrain is located within a 100-year floodplain
2) Flash floods and other flood events regularly occur during rainstorms in San Diego County

3) There were 10 Proclaimed States of Emergency from 1950 to 2009 due to floods in San Diego County

Much of the current work on inland flooding revolved around the 100-year and 500-year flood events. A great deal of work has been done by FEMA's National Flood Insurance Program (NFIP) in the San Diego County area, and results have been utilized and referenced in several publications. Inland flooding may be impacted by changes in precipitation patterns. Research on projected changes in precipitation indicates that there will be fewer precipitation events, but that these events will become more intense. Specifically, it is projected that there will be 16% fewer rainy days but 8% more rainfall during the biggest rainstorm events by 2050 (SANDAG 2014). Inland flooding tends to be associated with intense rain events, so these projected precipitation changes could correspond with more flooding events.

FEMA has also produced Flood Insurance Studies (FIS) which statistically evaluate the river flow, storm tides, hydrologic and hydraulic analyses, wave run-up, rainfall and topographic surveys. The various volumes describe in detail the specific topographic profiles, the methodology, and the historic observations of storm events. The results of the FIS are incorporated into the Flood Insurance Rate Maps (FIRM) which define the extents of various hazards and define the flood insurance premiums. FEMA maps do not include coastal erosion or SLR. Revised maps are currently being developed and are expected to be available for the San Diego Region in 2018.

The California Department of Water Resources (DWR) 2013 guidance document *California's Flood Futur*e: *Recommendations for Managing the State's Flood Risk* states that climate change may cause 100-year and 500-year floodplains to expand, due to changes in precipitation and runoff patterns, and sea level rise. Research also suggests that flood frequency and severity in California is likely to increase under projected climate changes.

Currently, a CEC-funded study led by Dr. Amir Aghakouchak and Dr. Jack Brouwer is investigating the impacts of climate change on extreme precipitation and inland flooding within Southern California. The authors are performing an intensity-duration-frequency curve analysis of precipitation extremes for a range of climate change scenarios currently under development by Scripps Institute of Oceanography, and will explore the cascading effect of changes in riverine flooding. In addition, the project will study the compounding impacts of land subsidence, SLR, and extreme precipitation.

Landslides and Mudslides

The San Diego County HMP indicates that landslides and mudslides pose a threat in SDG&E territory due to the terrain's steep slopes, weak claystone beds, and earthquake zones. Within the region, the western coastal plains and the eastern granitic mountains are the most prone to landslides. The HMP reports that many landslides occurred previously in the region under wetter climatic conditions. While there have been several landslides, there have been only two States of Emergency proclaimed in the County due to landslides. The San Diego County HMP characterize landslides and mudslides as the following:

> *Landslide*- the movement of masses of rock, earth or debris down a slope. Oftentimes, landslides are accompanied by other hazards including floods, earthquakes, and volcanic eruptions. Most commonly, landslides are caused by oversteepening, or an increase in downslope gravitational stress. Oversteepening can be induced by human activities, such as development or excessive irrigation, or natural processes, such as stream or wave erosion or heavy precipitation. A frequent cause of oversteepening is slope wash, or the erosion of slopes by surface water from heavy precipitation, excessive irrigation, or other human sources. Slope wash intensity is determined by runoff volume and velocity and the surface material resistance. Within urban and suburban areas, runoff volume and velocity is significantly higher, as the land is primarily covered by impermeable paved surfaces that fail to slow runoff.
>
> *Mudslide*- the flow of liquid mud down a slope. The primary cause is the accumulation of subsurface water and subsequent intense rainfall. The absence of vegetation bolstering the soil also enables mudslides to flow more freely.

A study by Ren et al. (2014) found that it is likely that Southern California landslides will increase in frequency and intensity during the twenty-first century. Furthermore, the study found that landslide locations are projected to change, indicating that previously stable areas could become susceptible to landslides. To estimate projected changes in storm-triggered landslide activity for Southern California, the authors used a 3-D, process-based landslide model (SEGMENT-Landslide) (Ren et al., 2014).

Qualitative estimates of changes in landslide probability can be made based on projected impacts of climate change on extreme precipitation in California. While mean precipitation is expected to undergo only modest changes, precipitation extremes are expected to increase significantly, leading to increased inter-annual variability (Berg and Hall, 2014; He and Gautam, 2016). Berg and Hall (2014) analyzed the output of 34 General Circulation Models and found that 50% projected statistically significant increase in wet extremes between 2020 and 2060, and a majority of models projected an increased frequency of dry and wet extremes between 2060 and 2100 in California. Similarly, He and Gautam (2016) found a projected increase in precipitation variability, and an associated increase in the occurrence of dry and wet extremes in California. These findings projecting an increase in frequency of wet extremes indicate that there is potential for an increase in frequency of precipitation-induced landslides.

Extreme Heat

The California Energy Commission's Cal-Adapt website defines an extreme heat day as a day in April through October where the maximum temperature exceeds the 98th historical percentile of maximum temperatures based on daily temperature maximum data between 1961 and 1990. Cal-Adapt defines a heat wave as five or more consecutive extreme heat days.

San Diego County's HMP defines extreme heat as temperatures that hover 10 degrees or more above the average high temperature for the region and last for several weeks. Based on this definition, The HMP excluded extreme heat from the hazard assessment stating that "*prolonged heat waves [were] not a historically documented hazard in the region.*" Similarly, Cal-Adapt's Extreme Heat Tool indicates that the SDG&E territory has had an historical average of only four extreme heat days per year.

Throughout this century, extreme heat days and heat waves are expected to significantly increase in frequency, magnitude and duration. By 2100, extreme heat days are expected over one quarter of the year (>100 days) in SDG&E territory (Cal Adapt, 2016; California Climate Action Team, 2013). By 2050, San Diego can expect the heat wave season of July through August (2 months) to expand to June through September (4 months). It can also expect Mean Temperature increases between 1.5°F to 4.5°F, with 4.8°F annual average increase by 2050 and between 2.2°F to 5.4°F by 2100. Furthermore, heat waves are expected to become more humid, reducing the amount of nighttime cooling (Climate Education Partners, 2014).

In urban areas, extreme heat will be compounded by the urban heat island effect. This phenomenon causes daytime temperatures in urban areas to be on average 1 to 6°F higher than in rural areas, and nighttime temperatures to be up to 22°F higher, due to the gradual heat release by buildings and pavement (California Climate Action Team, 2013).

The ICF team also conducted an interview with Dr. Alex Hall who is leading a CEC 4th Climate Change Assessment grant effort to look at the overall relationship between extreme temperatures and the energy grid in Los Angeles County (*Climate Change in Los Angeles County: Grid Vulnerability to Extreme Heat*). This study is the first-of-its kind in connecting fine-scale climate data, energy-use data, and grid capacity data. The project aims to increase understanding of the relationship between local electricity demand and the capacity of the grid under extreme heat events. While not directly related to Natural Gas, lessons learned from the approach and findings could be applied to this project.

Wildfire

The San Diego County HMP describes a wildfire as an uncontrolled fire spreading through vegetative fuels and exposing or possibly consuming structures. They often begin unnoticed and spread quickly. Naturally occurring and non-native species of grasses, brush, and trees fuel wildfires. A wildland fire is a wildfire in an area in which development is essentially nonexistent, except for roads, railroads, power lines and similar facilities. An Urban-Wildland/Urban Interface fire is a wildfire in a geographical area where structures and other human development meet or intermingle with wildland or vegetative fuels. There is significant development in San Diego County located along canyon ridges at the wildland/urban interface. Areas that have experienced prolonged droughts or are excessively dry are at risk of wildfires.

People start more than 80 percent of wildfires, usually as debris burns, arson, or carelessness. Lightning strikes are the next leading cause of wildfires. Wildfire behavior is based on three primary factors: fuel, topography, and weather. San Diego County has historically experienced wildfires on a regular basis, with ten States of Emergency declared due to wildfire between 1950 and 2015. The region is particularly vulnerable to wildfire, due to three of the region's characteristics:

1) Fuel. Abundance, continuity, moisture content, and burning qualities of fuel impact wildfire susceptibility. In San Diego, much of the region is covered with chaparral shrubs, which provide a significant fuel load for wildfires.
2) Topography. The terrain shape and slope impact air movements, fire movement speed, and firefighters' ability to access and extinguish the fire. Much of San Diego is composed of semi-arid coastal plains and rolling highlands, fostering fire movement.
3) Weather. Various weather variables impact wildfire intensity and length, including temperature, humidity and wind. San Diego experiences high temperatures, a dry climate, and warm and dry Santa Ana winds, the combination of which increase the probability of wildfires.

Dr. LeRoy Westerling has conducted the CEC-funded projects Scenarios to Evaluate Long-Term Wildfire Risk in California: New Methods for Considering Links Between Changing Demography, Land Use, and Climate (2012) and Potential Effects of Climate Change on Residential Wildfire Risk in California (2009). The Bryant & Westerling study (2009) found that wildfire risk is projected to increase through 2100 in California, with residential risk potentially quadrupling by mid-century, and further increasing through 2100. Large wildfire probability is expected to increase throughout the state, though the most significant increase is expected to occur within northern California's mountains and foothills, due to higher flammability induced by warmer and drier conditions. Regarding differences due to emissions scenarios, the projects indicated that the low (B1) and high (A2) scenarios produce little difference in risk through 2065, however the higher emission scenario, A2, leads to 20-30% higher risk during 2070-2100. The study found that wildfire spatial distribution was independent of the emission scenario. The study also notes that California's fire regimes are diverse, and therefore spatially explicit wildfire scenarios are critical to elicit region-specific details.

A study by Lenihan et al. (2003) investigated the impact of climate change on vegetation and associated fire hazard. This study found that in the projected drier climate, fire regime changes will be more significantly impacted by changes in the amount and character of fuels, as opposed to by changes in fire weather. The study indicates that the fire regime is likely to increase in year-to-year variability and in the number of extreme events.
Various sources exist for mapping current wildfire hazard, including those from the California Department of Forestry and Fire Protection (Cal Fire) and SDG&E. Cal Fire has produced Fire Hazard Severity Zone maps that evaluate fire hazard severity. PRC 4201 - 4204 and Govt. Code 51175-89 directed Cal Fire to map areas of significant fire hazards based on fuels, terrain, weather, and other relevant factors. These zones, referred to as Fire Hazard Severity Zones (FHSZ), define the application of various mitigation strategies to reduce risk associated with wildland fires. The FHSZ dataset provides draft boundaries for Very High FHSZs within Local, State and Federal Responsibility Areas (LRAs, SRAs, and FRAs). It is notable that Cal Fire is currently remapping FHSZs for SRAs and Very High Fire Hazard Severity Zones (VHFHSZ) in LRAs to provide updated map zones, based on new data, science, and technology.

The most detailed spatial data of existing wildfire hazard is the fire threat and fire risk zone data that SDG&E has developed. This data includes high resolution mapping of historical fires and existing fuel loads, categorized by vegetation type, from which fire risk can be extrapolated.

The Cal-adapt tool provides data on future wildfire potential for some parts of the SDG&E services territory, including most inland areas. However, SDG&E maintains a robust structure, including dedicated staff and systems to understand current wildfire risk. In subsequent tasks, the ICF team will draw on the SDG&E expertise and available data to inform our assessment of natural gas asset exposure to current wildfire hazards.

The ICF team conducted a series of interviews with Dr. Westerling to enhance our understanding of the ongoing research. Dr. Westerling is expected to produce updated wildfire projections through an ongoing CEC-funded project investigating electricity sector wildfire risk, titled Modeling the Impact of Wildfires on California's Transmission and Distribution Grid. The ICF team will further develop the approach for analyzing future wildfire hazard as part of the exposure analysis in future tasks.

Inland Hazard Modeling

As mentioned under the SLR Efforts section, FEMA has a coastal flooding Loss Estimation model called Hazus. The Hazus model has additional modules that look at other hazards (earthquakes, hurricanes, and riverine flooding) and estimate potential damage. While the Hazus model does not take into account climate change variables, the model is able to import hazard data that is reflective of climate change considerations. Similarly, the model is able to import customized data sets that enable users to gain a greater understanding of more realistic impacts, as opposed to using the 2010 Census default data.

3. Assets and Operations

The research for Natural Gas assets and operations centered on understanding the sensitivity of specific Natural Gas assets and operations, and their implications for the function on the Natural Gas system as a whole. The approach includes identifying key (critical) Natural Gas asset types and operation functions and then providing details on sensitivities identified through the literature review and interviews.

San Diego's Natural Gas system is a complex network of transmission and distribution components. The ICF team identified several general groups of key asset and operations types based on our knowledge of Natural Gas systems and review of utility vulnerability assessments (Table 19).

Table 19. Key Natural Gas asset and operation types

Key Asset Types	• Transmission Pipelines (high pressure) • Distribution Pipelines (low pressure) • Natural Gas Power Plants • Compressor Stations (including pump components) • Gate Settings and Distribution Regulating Stations • Storage Facilities • Communications & IT Equipment
Key Operations Types	• Emergency Response • Communications • Demand Forecasts & Long-Range Planning

Natural Gas systems, including specific assets and operations, may be sensitive to climate-related hazards. Sensitivity is defined as the degree to which the asset or operation could be impacted by a hazard if exposed. Design standards and guidance that specifically include climate change considerations do not exist. Existing standards, however, and awareness of how existing assets are impacted by current climate conditions (i.e., their sensitivity) facilitates assessment of what future climate conditions will exceed critical thresholds. Historic performance of assets in response to climate-related hazards can also reveal key sensitivities and adaptive capacity (the degree to which an asset or operation can adjust to potential impacts, quickly recover, and take advantage of opportunities).

The Pipeline and Hazardous Materials Safety Administration (PHMSA) is the federal authority for ensuring Natural Gas pipeline safety. The PHMSA monitors compliance with existing regulation and ensures that Natural Gas system operators are meeting expected safety levels. The Code of Federal Regulations (Title 49 Subtitle B Chapter I Subchapter D Part 192) prescribes minimum safety requirements for pipeline facilities and the transportation of gas. California Public Utilities Commission (CPUC) Natural Gas design standards exist within General Order number 112. The specifications used do not provide climate stressor thresholds that the infrastructure must withstand, however, the specifications used do not provide climate stressor thresholds that the infrastructure must withstand.

Table 20 provides a summary of the types of impacts due to sensitivity of assets and operations exposed to coastal and inland hazards based on available public information. It also provides information on potential adaptation measures.

Table 20. Types of impacts due to sensitivity for assets and operations

		SLR & Coastal Hazards	Extreme Heat	Wildfire	Landslides/ Mudslides	Inland Flooding	Potential Adaptation Measures
Key Asset Types	**Transmission and Distribution Pipelines**	Coastal pipeline corrosion due to saltwater intrusion from SLR Direct damage from floating debris during periods of inundation Permanent inundation of water levels beyond design strength	Decreased pipe performance Accelerated degradation of pipe coating	Direct heat damage Temporary lack of accessibility	Impact damage Exposure of underground pipelines	Direct damage Destabilization Temporary lack of accessibility	Undergrounding Installing stabilizing features Replace leak-prone cast iron & steel pipe Install valves preventing water from entering high-pressure service vent lines Reinforce floodwalls Build new floodwalls and storm surge barriers Integrate coastal wetlands restoration to protect coastal pipelines
	Natural Gas Power Plants	Direct damage from flooding Power outages Temporary or permanent lack of accessibility	Decreased efficiency	Direct heat damage Temporary lack of accessibility	Impact damage	Service interruptions Power outages Temporary lack of accessibility	Elevate key components Install improved pumping equipment & back-up generators to remove water that intrudes Reinforce floodwalls Build or rebuilding assets in a new location Build new floodwalls and storm surge barriers Integrate coastal wetlands restoration to protect coastal stations

	SLR & Coastal Hazards	Extreme Heat	Wildfire	Landslides/ Mudslides	Inland Flooding	Potential Adaptation Measures
Compressor Stations, Gate Settings, and Distribution Regulating Stations**	Direct damage from flooding Power outages Temporary or permanent lack of accessibility	Decreased component performance Power outages	Direct damage from flooding Power outages Temporary lack of accessibility	Impact damage	Service interruptions Power outages Temporary lack of accessibility	Elevate stations or key components Install improved pumping equipment & back-up generators to remove water that intrudes Reinforce floodwalls Use submersible equipment Build or rebuilding assets in a new location Build new floodwalls and storm surge barriers Integrate coastal wetlands restoration to protect coastal stations
Storage Facilities	Water infiltration to gas distribution equipment and tunnels Permanent inundation		Temporary lack of accessibility	Impact damage	Temporary lack of accessibility	Install hardened reinforced concrete tunnel entrances designed to prevent or greatly reduce water intrusion
Communications and IT Equipment	Direct damage from flooding Permanent inundation Temporary or permanent lack of accessibility	Power outages Decreased component performance	Direct heat damage Damage from smoke and soot	Impact damage	Water damage to circuitry Temporary lack of accessibility	Backup solutions for communications systems remotely monitoring & controlling gas system pressures & flows Expand use of water-resistant fiber-optic communications and control systems (as opposed to copper wires) enabling for remotely operated equipment during flooding

Key Operations Types		SLR & Coastal Hazards	Extreme Heat	Wildfire	Landslides/ Mudslides	Inland Flooding	Potential Adaptation Measures
	Emergency Response	Direct impact or loss of access to corporate (maintenance) yards for stockpiled resources Fuel unavailable for emergency response vehicles due to loss of power Loss of access, damage to critical infrastructure (i.e., roadways, bridges) needed for response					Review existing protocols and policies for climate change considerations Preposition equipment, resources, and supplies Participating in Mutual Assistance Groups
	Communications	Direct impact and loss of services for cell towers hindering service in the field Risks due to gradual change not captured in existing communication protocols or strategies					Upgrading control centers & communication equipment Communicate with fellow employees about potential areas where the system might experience power outages
	Demand Forecasts & Long-Range Planning	Long-term changes to load centers due to permanent inundation Insufficient load following storm events	Sharp increases in demand Regional system impacts	Increase in maintenance costs reduced operating efficiencies		Insufficient load following storm events	Purchase large mobile generators (i.e., Gensets) and transformers to help recover more quickly from power losses Integrating system changes to enhance resilience in long-range asset planning, including revised design standards such as height above Base Flood Elevation for critical assets Review emergency management protocols and policies New or modified indemnity-based insurance

**some assets and operations were combined in this table for readability due to common potential sensitivities.

Consideration will also be given to asset and operation dependencies and interdependencies (i.e., need for water, electricity, and natural gas) to explore possible cascading sensitivities that could impact maintaining functionality.

The interviews with the utility companies confirmed that during the DOE vulnerability assessment development process that many undertook vulnerability assessments at a strategic level for the purpose of planning and analysis, as a means of engaging staff across the utility on the climate change issue, and/or focused their assessments on critical or key assets or operations. Many utilities indicated in their vulnerability assessments a need, through additional studies, to consider climate change impacts at an asset-by-asset and operational level. Interviews conducted with utilities impacted by Superstorm Sandy provided insights into the detailed asset-by-asset analysis undertaken to plan for, and to prioritize, the response to the specific flood impacts due to Storm Surge.

4. Preliminary Results

Sea Level Rise and Coastal Hazards

As discussed in previous sections, the USGS has produced preliminary results of the Coastal Storm Modeling System (CoSMoS) from four SLR scenarios: 50 cm (0.5 m), 100 cm (1.0 m), 150 cm (1.5 m) and 200 cm (2.0 m). While different assumptions and more detail will be applied to the final CoSMoS 3.0 data release in the months to come, an initial analysis has been done overlaying the preliminary data with SDG&E natural gas assets. From this analysis, we receive an early indication of the linear footage of natural gas assets potentially impacted by sea level rise, as well as the number of natural gas point assets (Table 21 and Table 22 below). While these results will be refined with the final CoSMoS 3.0 data release, the early numbers will allow planning of adaptation strategies to begin.

Table 21. Linear footage of natural gas assets potentially impacted by sea level rise

	Linear Feet of Gas Assets*							
SLR (cm)	Gas Pipe Casing	HP Pipe	HP Service Pipe	Misc Gas Line	MP Pipe	MP Service Pipe	Grand Total	Percent Impacted
50	15,962	30,691	N/A	171	125,636	103,874	276,334	0.34%
100	27,004	57,240	1,167	751	264,233	190,908	541,303	0.66%
150	41,112	80,613	2,045	1,426	388,264	260,938	774,398	0.94%
200	55,554	113,143	2,611	1,771	561,828	375,253	1,110,160	1.35%

*All data are preliminary and produced for demonstration purposes only.

Table 22. Number of natural gas point assets potentially impacted by sea level rise

	Number of Point Gas Assets*						
SLR (cm)	Controllable Gas Valve	Excess Flow Valve	Non Controllable Fitting	Regulator	Service Connection	Grand Total	Percent Impacted
50	99	26	659	1	3,731	4,516	0.46%
100	229	64	1,295	4	6,026	7,618	0.77%
150	388	90	1,850	12	7,682	10,022	1.01%
200	600	107	2,687	22	10,360	13,776	1.39%

*All data are preliminary and produced for demonstration purposes only.

Inland Flooding

The inland flooding projections were determined using SDG&E infrastructure overlaid on the Federal Emergency Management Agency (FEMA) 100-year flood zones. From this analysis, we receive an indication of the linear footage of natural gas assets and the number of natural gas point assets potentially impacted by inland flooding.

Table 23. Linear footage of natural gas assets potentially impacted by inland flooding

	Linear Feet of Gas Assets*							
FEMA Flood Hazard Description	Gas Pipe Casing	HP Pipe	HP Service Pipe	Misc Gas Line	MP Pipe	MP Service Pipe	Grand Total	Percent Impacted
0.2 PCT ANNUAL CHANCE FLOOD HAZARD	29,510	114,307	459	1,211	1,280,001	1,023,941	2,449,429	2.99%
An area inundated by 100-year flooding (usually an area of ponding), for which BFEs have been determined; flood depths range from 1 to 3 feet.	30,127	122,112	459	1,211	1,308,780	1,047,602	2,510,291	3.06%
An area inundated by 100-year flooding (usually sheet flow on sloping terrain), for which average depths have been determined; flood depths range from 1 to 3 feet.	31,747	143,294	459	1,262	1,395,403	1,104,249	2,676,414	3.26%
An area inundated by 100-year flooding, for which BFEs have been determined.	54,029	237,371	496	2,378	1,748,788	1,217,331	3,260,393	3.98%
An area inundated by 100-year flooding, for which no BFEs have been determined.	65,540	296,446	741	3,433	1,899,744	1,335,782	3,601,686	4.39%
An area inundated by 100-year flooding, for which no BFEs have been determined. This is an area to be protected from the 100-year flood by a Federal flood protection system under construction.	67,518	304,688	823	3,628	2,056,405	1,445,687	3,878,749	4.73%
An area inundated by 100-year flooding with velocity hazard (wave action); BFEs have been determined.	67,519	304,688	823	3,628	2,056,405	1,446,168	3,879,231	4.73%
An area of undetermined but possible flood hazards.	70,996	519,941	3,701	4,116	2,337,327	1,622,298	4,558,379	5.56%

*All data are preliminary and produced for demonstration purposes only.

Table 24. Number of natural gas point assets potentially impacted by inland flooding

	Number of Point Gas Assets*							
FEMA Flood Hazard Description	Controllable Gas Valve	Excess Flow Valve	Non Controllable Fitting	Non Controllable Gas Valve	Regulator	Service Connection	Grand Total	Percent Impacted
0.2 PCT ANNUAL CHANCE FLOOD HAZARD	833	134	5,105	N/A	28	24,392	30,492	3.08%
An area inundated by 100-year flooding (usually an area of ponding), for which BFEs have been determined; flood depths range from 1 to 3 feet.	883	136	5,264	N/A	32	24,778	31,093	3.14%
An area inundated by 100-year flooding (usually sheet flow on sloping terrain), for which average depths have been determined; flood depths range from 1 to 3 feet.	990	137	5,711	N/A	36	26,229	33,103	3.35%
An area inundated by 100-year flooding, for which BFEs have been determined.	1,311	179	7,271	N/A	45	29,615	38,421	3.88%
An area inundated by 100-year flooding, for which no BFEs have been determined.	1,464	191	7,929	N/A	51	31,008	40,643	4.11%
An area inundated by 100-year flooding, for which no BFEs have been determined. This is an area to be protected from the 100-year flood by a Federal flood protection system under construction.	1,571	191	8,418	1	52	33,511	43,744	4.42%
An area inundated by 100-year flooding with velocity hazard (wave action); BFEs have been determined.	1,572	191	8,418	1	52	33,512	43,746	4.42%
An area of undetermined but possible flood hazards.	1,808	392	9,461	1	79	36,574	48,315	4.88%

*All data are preliminary and produced for demonstration purposes only.

Landslides

Landslide data was produced and distributed in a Geohazards data layer by San Diego Geographic Information Source (SanGIS), a local information source that provides map making, data extraction, and other services for San Diego County. Steep slopes as used in these preliminary results are defined by the County of San Diego Planning & Development Services as any slopes greater than 25%. From this analysis, we receive an initial indication of the linear footage of natural gas assets and the number of natural gas point assets potentially impacted by landslides (Table 25 and Table 26).

Table 25. Linear footage of natural gas assets potentially impacted by landslides

	Linear Feet of Gas Assets*						
Geo Hazard	Gas Pipe Casing	HP Pipe	Misc Gas Line	MP Pipe	MP Service Pipe	Grand Total	Percent Impacted
LANDSLIDES							
not steep slope	2,304	2,037	N/A	151,227	130,249	285,817	0.35%
steep slope	450	951	N/A	16,021	14,229	31,651	0.03%
SLIDE PRONE FORMATIONS							
not steep slope	14,649	76,574	307	1,453,137	1,331,040	2,875,707	3.51%
steep slope	1,985	20,791	98	101,921	53,381	178,176	0.22%

*All data are preliminary and produced for demonstration purposes only.

Table 26. Number of natural gas point assets potentially impacted by landslides

	Number of Point Gas Assets*						
Geo Hazard	Controllable Gas Valve	Excess Flow Valve	Non Controllable Fitting	Regulator	Service Connection	Grand Total	Percent Impacted
LANDSLIDES							
not steep slope	40	3	406	1	3,249	3,699	0.37%
steep slope	8	1	51		380	440	0.04%
SLIDE PRONE FORMATIONS							
not steep slope	634	173	4,454	13	32,476	37,750	3.82%
steep slope	62	22	353	6	1,067	1,510	0.15%

*All data are preliminary and produced for demonstration purposes only.

Wildfires

Wildfire impacts were investigated by overlaying SDG&E infrastructure over maps of the SDG&E-defined Fire Threat Zone and High Risk Fire Area. From this analysis, we receive an initial indication of the linear footage of natural gas assets and the number of natural gas point assets potentially within the most at-risk areas to wildfire within the service territory (Table 27 and Table 28).

Table 27. Linear footage of natural gas assets potentially impacted by wildfires

SDG&E Fire Zones		**Linear Feet of Gas Assets***							
SDGE_FTZ	SDGE_HFRA	Gas Pipe Casing	HP Pipe	HP Service Pipe	Misc Gas Line	MP Pipe	MP Service Pipe	Grand Total	Percent Impacted
Fire Threat Zone	High Risk Fire Area	1,993	57,699	5	389	263,155	163,342	486,583	0.59%
Fire Threat Zone	Not High Risk Fire Area	15,860	441,670	686	2,511	2,855,443	2,077,916	5,394,086	6.58%

*All data are preliminary and produced for demonstration purposes only.

Table 28. Number of natural gas point assets potentially impacted by wildfires

SDG&E Fire Zones		**Number of Point Gas Assets***						
SDGE_FTZ	SDGE_HFRA	Controllable Gas Valve	Excess Flow Valve	Non Controllable Fitting	Regulator	Service Connection	Grand Total	Percent Impacted
Fire Threat Zone	High Risk Fire Area	113	12	716	11	2,704	3,556	0.36%
Fire Threat Zone	Not High Risk Fire Area	1,052	2,288	8,861	80	44,162	56,443	5.70%

*All data are preliminary and produced for demonstration purposes only.

5. Adaptation Measures

In general, utilities can address climate vulnerabilities to their assets, operations, and systems (implement adaptation measures) through: 1) hardening of existing assets; 2) new construction and relocation; 3) policy and planning; 4) ecosystem-based measures; and 5) risk transfer. Implementing a portfolio of adaptation measures (including a combined set of different types to exploit beneficial synergies) can help to address the vulnerabilities and avoid the potential direct and indirect costs from SLR and inland hazards (DOE 2010, GAO 2014).

In California, utilities have disclosed strategic-level adaptation measures; research did not discover asset-specific adaptation measures. The adaptation measures consist of broad descriptions of emergency management planning; coordination with first responders and emergency officials; and planning and analysis measures. SANDAG's *Climate Action Strategy* focuses on adaptation measures to consider when addressing impacts to transportation and energy infrastructure for a limited set of climate change hazards. Based on data from the *Climate Action Strategy,* SANDAG developed *the Climate Change Mitigation and Adaptation White Paper* which includes recommendations for a regional approach to address climate change, and a summary of current efforts in the San Diego region.

The vulnerability assessment conducted by Con Edison provided detailed information on actions needed to enhance system resiliency (including assets, operations and management practices). For example, Con Edison has implemented infrastructure flood resilience design standards that take into consideration more extreme events, and, therefore, allow for higher flood levels relative to standard utility infrastructure. Specifically, Con Edison infrastructure is built to FEMA flood levels plus 3 feet, while PSE&G is built to FEMA flood levels plus 1 foot. PSE&G uses the New Jersey Department of Environmental Protection (NJDEP) flood hazard area rules based on FEMA post-Superstorm Sandy flood elevations. Adaptation measures were also found in storm hardening plans focused on the East and Gulf Coasts; several utilities from the states of New York, New Jersey, Maryland, Arkansas, Louisiana, Mississippi and Texas have filed for storm hardening funding in order to build energy infrastructure resilience. Con Edison and National Grid of New York during and post Superstorm Sandy also employed operational changes to build resilience. As Superstorm Sandy approached, the two utilities isolated some low-lying parts of their networks to ensure that the impact of the intrusion of water would be limited, rather than spreading system-wide.

E. Summary

Below is a summary of the significant findings from this literature review and discussion of implications for the tasks that the team will undertake next.

<u>Sea Level Rise</u>

1. The preliminary CoSMoS 3.0 coastal hazard model includes the necessary SLR-related processes (i.e., SLR, wave run-up, and coastal erosion) and its results are appropriate to provide a preliminary coastal hazard overlay for SDG&E assets. The ICF team will use the preliminary information to test geospatial analysis techniques at the outset of Task 3, which will promote rapid integration of the final CoSMoS 3.0 model results once they are available.
2. Under Task 3, the ICF team will take several actions to ensure the best available science is appropriately applied for the SDG&E service territory:
    a) Interpret results from Scripps Institute of Oceanography's probabilistic regional SLR scenarios to compare against final CoSMoS 3.0 model results
    b) Validate the results from final CoSMoS 3.0 model against the SPAWAR model results, FEMA FIRM, and maps of previous SLR assessments to ensure the applicability of the results in the San Diego coastal region.
    c) Verify existing coastal flood and erosion mitigation infrastructure (e.g., sea walls, berms) through remote and land-based surveys to confirm the quality of data included within final CoSMoS 3.0 model results.
    d) Interpret final CoSMoS 3.0 results to align with key planning time periods (e.g., 2030 and 2050) and SLR scenarios provided by the CEC.

Assets and Operations

3. The research discovered information on general climate-related hazard sensitivity thresholds for Natural Gas assets, but the level of detail is not sufficient to inform asset-specific analysis. Therefore, further work will be done under Task 3 with SDG&E subject matter experts to better understand the sensitivity of specific SDG&E key (critical) assets.
4. The literature review did not provide sufficient information to determine critical, priority Natural Gas assets within the SDG&E system; many of the documents reviewed lacked asset-specific focus. Additional work with SDG&E subject matter experts will be conducted under Task 3 to analyze the criticality of assets and operations to the system function.

Adaptation Measures

5. There is a significant amount of information on general risk mitigation strategies, methods, and best practices that utilities have undertaken or plan to undertake from a business risk perspective that should be leveraged to identify adaption measures. The applicability of these risk management strategies to support adaptation will be furthered explored in subsequent tasks.
6. To build upon the general adaptation measures identified through the literature review, additional work under Task 6 will need to be done with SDG&E subject matter experts to help guide the development of potential adaptation measures relevant to the SDG&E context.

Inland Hazards

7. Regionally-specific hazard data layer is available for modeling existing inland flooding, wildfire and extreme heat within the SDG&E territory.
    a. There is information regarding the key climate change driver for inland flooding (i.e., increased precipitation) that can be used to adjust the regionally-specific hazard data layer. Additional work will need to be done under Task 3 to determine appropriate method for incorporation.
    b. Work is being conducted concurrently under the 4th Climate Change Assessment (by Dr. Westerling) that plans to provide climate change driven changes in wildfires. The ICF team will continue to coordinate and track progress under Task 3 to determine how best to leverage and incorporate results.
    c. Work is being conducted concurrently under the 4th Climate Change Assessment to develop an enhanced Cal-Adapt extreme heat tool. The ICF team will coordinate with CEC under Task 3 to determine how best to incorporate results from the enhanced Cal-Adapt extreme heat tool
8. A regionally-specific hazard data layer is not available for modeling existing landslides/mudslides within the SDG&E territory.
    a. Building on the literature review, the ICF team will conduct additional work under Task 3 to develop an existing hazard data layer for both landslides/mudslides.
    b. There is climate change information (i.e., increased precipitation, increased temperature) and current resource data (i.e., geo-hazard areas, soils types, climate, topography) that can be used to adjust the regionally-specific hazard layer. Additional work will need to be done under Task 3 to determine appropriate incorporation.

Conclusion

San Diego Gas & Electric's (SDG&E) commitment to climate change and the Department of Energy's Partnership for Energy Sector Climate Resilience has never been greater. SDG&E acknowledges the changing climate and resulting potential for extreme weather events and finds it important to determine the level of impacts of a changing climate, both to the utility and to its customers. SDG&E is committed to applying this knowledge to resilience measures being adopted by the company as it strives to build a system more hardened to the occurrence of severe weather and climate-related hazards to come.

In the months and years to come, SDG&E will continue to prioritize the need for adaptation to a changing climate by including climate as an enterprise risk and identifying its potential long-term impacts on existing enterprise risks. This process will be the mechanism for the continued integration of climate into the core business of SDG&E.

References

Amir Aghakouchak Pers. Comm. (2016). Interview about A Multi-Hazard Investigation of Climate Vulnerability of the Natural Gas Energy System in Southern California. ICF International.

Ananda Kanapathy Pers. Comm. (2016) *Interview about PSE&G Climate Resilience/Interviewer: ICF International*.

Audinet, P., Amado, J., & Rabb, B. (2014). Climate Risk Management Approaches in the Electricity Sector: Lessons from Early Adapters. *Weather Matters for Energy, Springer New York*, 17-64.

Berg, N. and A. Hall (2015). "Increased inter-annual precipitation extremes over California under climate change." Journal of Climate 28(16): 6324-6334.

Bryant, B. and A. L. Westerling (2009). Potential effects of climate change on residential wildfire risk in California, California Climate Change Center.

Bryant, B. and A. L. Westerling (2012). Scenarios to evaluate long-term wildfire risk in California: New methods for considering links between changing demography, land use, and climate, California Energy Commission.

Buckley, David; Scott, Joe; Ramirez, Joaquin; Monedero, Santiago, Vacarro, Joe. 2014. SDG&E Wildfire Risk Reduction Model – Design Report. San Diego Gas & Electric Company, October 2014. 59 p.

Buckley, David; Scott, Joe; Ramirez, Joaquin; Monedero, Santiago. 2013. Feeder Line Wildfire Risk Analysis Pilot Project Final Report. Arizona Public Service. 29 p.

Buckley, David; Carlton, Don; Hoyt, Janet; Wolf, Jim. 2013. West Wide Wildfire Risk Assessment Final Report. Oregon Dept. of Forestry. 105 p.

Buckley, David; Berry, Joseph; Scott, Joe. 2013. Colorado Wildfire Risk Assessment Final Report. Colorado State Forest Service. 80 p.

Buckley, David; Carlton, Don; Heartwell, Rebecca. 2012. San Diego County Wildfire Risk Assessment and Economic Impact Analysis Final Report. San Diego County Fire Authority. 71 p.

Buckley, David; Scott, Joe; Stripling, Curt. 2012. Texas Wildfire Risk and Fire Effects Final Report. Texas A&M Forest Service, 74 p.

Buckley, David; Boissonnade, Auguste; Schlumberger, Marc-Etienne. 2006. California Insurance Wildfire Risk Model Design Specifications. Risk Management Solutions, Inc. 89 p.

CA DWR (2013). California's flood future: recommendations for managing the State's flood risk, California Department of Water Resources (DWR) and Natural Resources Agency (NRA).

Cal-Adapt (2016). Temperature: Extreme Heat Tool. California Energy Commission.

California Climate Change Center (2006). Our Changing Climate: Assessing Risks to California. A Summary Report from the California Climate Change Center. California Energy Commission. California Environmental Protection Agency.

California Climate Change Center (2012). Our Changing Climate 2012: Vulnerability & Adaptation to the Increasing Risks from Climate Change in California. A summary report on the Third Assessment from the California Climate Change Center., California Third Climate Change Assessment.

California Coastal Commission (2015). Interpretive Guidelines for Addressing Sea Level Rise in Local Coastal Programs and Coastal Development Permits. C. C. Commission. Sacramento, CA. California Coastal Commission Sea Level Rise Policy Guidance.

Cayan, D., Tyree, M., Pierce, D. W., & Das, T. (2012). *Climate Change and Sea Level Rise Scenarios for California Vulnerability and Adaptation Assessment*. Retrieved from http://www.energy.ca.gov/2012publications/CEC-500 2012-008/CEC-500-2012-008.pdf

Chadwick, B. (2014). A methodology for assessing the impact of sea level rise on representative military installations in the Southwestern United States (RC-1703). The Strategic Environmental Research and Development Program, SPAWAR Systems Center Pacific.

Chandramowli, S. N. (2015). *Impact of climate change on electricity systems and markets.* (Doctor of Philosophy), Rutgers, New Brunswick, NJ.

Chang Consultants. (2010). Appendix B: Hydraulic and scour studies for proposed Interstate 5 bridge widening across three lagoons *San Diego Regional Lagoon Planning Studies Phase 2*.

City of Encinitas. (2015). *Encinitas-Solana Beach Coastal Storm Damage Reduction Project Integrated Feasibility Report & Environmental Impact Statement/Report (EIS/EIR)*.

City of San Diego (2015). Climate Action Plan. Krout Associates and Energy Policy Initiatives Center. https://www.sandiego.gov/sites/default/files/final_december_2015_cap.pdf.

County/City of San Francisco (2015). Guidance for Incorporating Sea Level Rise into Capital Planning in San Francisco: Assessing Vulnerability and Risk to Support Adaption

Con Edison (2013). Post Sandy Enhancement Plan. http://www.coned.com/publicissues/PDF/post_sandy_enhancement_plan.pdf, Consolidated Edison Company of New York (Con Edison).

Con Edison (2015). Appendix F. Storm Hardening and Resiliency Collaborative Phase Three Report, Consolidated Edison Company of New York Inc.

CPUC. (2012). General Order 95 Rules for Overhead Electric Line Construction. http://www.cpuc.ca.gov/gos/GO95/go_95_startup_page.html: California Public Utilities Commission (CPUC).

Dettinger, M. (2011). "Climate change, atmospheric rivers, and floods in California - a multimodel analysis of storm frequency and magnitude changes." Journal of the American Water Resources Association (JWRA) 47(3): 514-523.

DOE (2010) Hardening and Resiliency U.S. Energy Industry Response to Recent Hurricane Seasons. Washington, D.C., U.S. Department of Energy (DOE).

DOE (2013). U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather. V. C. Tidwell, T. J. Wilbanks, M. Antes, G. Williams and C. W. Gillespie. Washington, D.C., U.S. Department of Energy (DOE).

DOE. (2016). Climate Change and the Electricity Sector: Guide for Assessing Vulnerabilities and Developing Resilience Solutions to Sea Level Rise. Retrieved from http://energy.gov/epsa/downloads/climate-change-and electricity-sector-guide-assessing-vulnerabilities-and-developing

DOE (Unpublished). DOE's Partnership for Energy Sector Climate Resilience: Vulnerability Assessment Summary Report. DOE's Partnership for Energy Sector Climate Resilience, U.S. Department of Energy (DOE).

Ebinger, J. and W. Vergara (2011). Climate Impacts on Energy Systems: Key Issues for Energy Sector Adaptation. World Bank Study. Washington, D.C., The World Bank: 178.

ESA (2016). DRAFT Coastal hazards, vulnerability, and risk assessment: Del Mar, CA. Environmental Science Associates (ESA).

Everest International Consultants (2004). Buena Vista lagoon restoration feasibility analysis. Carlsbad, CA, Buena

Vista Lagoon Foundation.

Everts Coastal, & California State Coastal Conservancy. (2002). *Impact of sand retention structures on Southern and Central California beaches*: California Coastal Conservancy.

FEMA (2016). FEMA Flood insurance Studies, Federal Emergency Management Agency (FEMA).

FEMA (2015). "Coastal Frequently Asked Questions." Coastal Flood Risks. Accessed in 2016, from http://www.fema.gov/coastal-frequently-asked-questions.

Finney, Mark. 2005. The Challenge of Quantitative Risk Analysis for Wildland Fire. Forest Ecology and Management. 12p.

Flick, R. E., et al. (2012). "'Flooding' versus 'inundation'." Eos 93(38): 365-366.

Fussel, H.-M. (2005) Vulnerability in Climate Change Research: A Comprehensive Conceptual Framework. *Breslauer Symposium. University of California International Area Studies*.

Gallien, T. (2016). "Validated coastal flood modeling at Imperial Beach, California: Comparing total water level, empirical and numerical overtopping methodologies." Coastal Engineering 111: 95-104.

GAO (2014). Energy Infrastructure Risks and Adaptation Efforts. Climate Change, U.S. Government Accountability Office.

Governor Edmund G. Brown Jr. (2015). Governor Brown declares state of emergency in California to bolster wildfire response. California Office of Governor Edmund G. Brown Jr.

Governor Edmund G. Brown Jr. (2014). Governor Brown declares state of emergency in San Diego County, Cal OES Governor's Office of Emergency Services.

He, M. and M. R. Gautam (2016). "Variability and trends in precipitation, temperature and drought indices in the state of California." Hydrology 3(2): 14.

ICLEI-USA. (2012). *Sea Level Rise Adaptation Strategy for the San Diego Bay*.

IPCC (2007). Appendix I Glossary. Contribution of Working Group II [Impacts, Adaptation, and Vulnerability] to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden and C. E. Hanson. Cambridge, United Kingdom and New York, NY, USA, Intergovernmental Panel on Climate Change (IPCC): 976.

IPCC (2012). Managing the risks of extreme events and disasters to advance climate change adaptation, Intergovernmental Panel on Climate Change (IPCC).

IPCC. (2014). *WGII AR5 Annex II: Glossary*. Retrieved from Cambridge, United Kingdom and New York, NY, USA: http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-AnnexII_FINAL.pdf

Lenihan, J. M., et al. (2003). "Climate change effects on vegetation distribution, carbon, and fire in California." Ecological Applications 13: 1667-1681.

Messner, S., Miranda, S., Green, K., Phillips, C., Dudley, J., Cayan, D., & Young, E. (2009). *Climate Change-Related Impacts in the San Diego Region by 2050*. Retrieved from http://www.energy.ca.gov/2009publications/CEC-500-2009-027/CEC-500-2009-027-F.PDF

Moffatt & Nichol (2015). Bridge hydraulics study for I-5 bridge over Batiquitos Lagoon. Final Hydraulics Report at 90% Design, SANDAG and Caltrans District 11.

National Oceanic and Atmospheric Administration (NOAA) Technical Report NOS CO-OPS 073 (2014).Sea Level Rise and Nuisance Flood Frequency Changes around the United States. Department of Commerce.

New York City (2013). "A Stronger, More Resilient New York - Ch 6 Utilities."

Ocean Studies Board. (2012). *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*: National Academies Press.

OPC (2016). Planning for Sea-Level Rise Database. C. N. R. A. a. t. O. P. Council. http://www.opc.ca.gov/climate-change/planning-for-sea-level-rise-database/.

Patsch, K. and G. Griggs (2007). Development of Sand Budgets for California's Major Littoral Cells, Institute of Marine Sciences.

PG&E (2015). Climate Change Vulnerability Assessment, Pacific Gas and Electric Company (PG&E).

Ralff-Douglas, K. (2016). Climate Adaptation in the Electric Sector: Vulnerability Assessments & Resiliency Plans. C. P. U. Commission. Retrieved from http://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/About_Us/Organization/Divisions/Policy_and_Planning/PPD_Work/PPD_Work_Products_(2014_forward)/PPD%20%20Climate%20Adaptation%20Plans.pdf.

Ren, D., et al. (2014). "Trends in storm-triggered landslides over Southern California." Journal of applied meteorology & climatology 53(3): 217-233.

Renato Derech Pers. Comm. (2016). [Interview about ConEdison Climate Resilience].

Revell Coastal (2016). City of Imperial Beach Sea Level Rise Study.

Rusco, F. (2014). *Energy Infrastructure Risks and Adaptation Efforts*.

SANDAG (2009). Coastal Regional Sediment Management Plan for the San Diego Regional. T. C. C. S. M. Workgroup, San Diego Association of Governments (SANDAG).

SANDAG. (2010). *Climate Action Strategy*. Retrieved from http://www.sandag.org/uploads/publicationid/publicationid_1481_10940.pdf.

SANDAG. (2014). *Climate Change Mitigation and Adaptation White Paper*. Retrieved from http://www.sdforward.com/sites/sandag/files/Climate_Change_White%20Paper_fwe_07142014.pdf

Sathaye, J. A., et al. (2013). "Estimating impacts of warming temperatures on California's electricity system." Global Environmental Change 23(2): 499-511.

Savonis, M. J., et al. (2008). Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I. Synthesis and Assessment Product 4.7. J. R. Potter, V. R. Burkett, M. J. Savonis and D. J. Dokken. Washington, D.C., U.S. Climate Change Science Program and the Subcommittee on Global Change Research.

San Diego County (2010). Multi-Jurisdictional Hazard Mitigation Plan. San Diego, CA, San Diego County.

Schaeffer, R., et al. (2012). "Energy sector vulnerability to climate change: a review." Energy 38(1): 1-12.

SDG&E (2016). Partnership for Energy Sector Climate Resilience. Part I. Vulnerability Assessment, San Diego Gas and Electric (SDG&E).

SDG&E (2016). SDG&E Regional Energy Sector Vulnerabilities and Resilience Strategies, San Diego Gas and Electric (SDG&E).

Scott, Joe; Helmbrecht, Don; Thompson, Matthew; Calkin, David; 2013. Integrated Wildfire Risk Assessment: Framework Development and Application on the Lewis and Clark National Forest in Montana, USA. Integrated Environment Assessment and Management, Volume 9999, Number 00. 14p.

Scott, Joe; Thompson, Matthew; Kaiden, Jeffrey; Gilbertson-Day, Julie; 2013. A Polygon-based Modeling approach to Assess Exposure of Resources and Assets to Wildfire. Nat Hazards. DOI 10.1007/s11069-013-0593-2. 18p.

Scott, Joe; Helmbrecht, Don; Thompson, Matthew; Calkin, David; Marcille, Kate . 2012. Probabilistic Assessment of Wildfire Hazard and Municipal Watershed Exposure. Nat Hazards. DOI 10.1007/s11069-012-0265-7. 22p.

Scott, Joe; 2006. An Analytical Framework for Quantifying Wildland Fire Risk and Fuel Treatment Benefit. USDA Forest Service Proceedings RMRS-P-41. 2006. 16p.

Scott, Joe H. and Robert E. Burgan. 2005. Standard Fire Behavior Fuel Models: A Comprehensive Set for Use with Rothermel's Surface Fire Spread Model. USDA Forest Service, Gen. Tech. Rpt. RMRS-GTR-153, Rocky Mountain Research Station, Ft. Collins, CO.

Seattle City Light. (2015). *Seattle City Light Climate Change Vulnerability Assessment and Adaptation Plan*. Retrieved from http://www.seattle.gov/light/enviro/docs/Seattle_City_Light_Climate_Change_Vulnerability_Assessment_and_Adaptation_Plan.pdf

Solana Beach (2014). "Local Coastal Plan, Ch4 Hazards Shoreline Bluff Development."

Sorensen, R. (1997). *Basic Coast Eng, 2nd Ed*. New York.

Stockdon, H. F., et al. (2006). "Empirical parameterization of setup, swash, and run-up." Coastal Engineering 53: 573-588.

The San Diego Foundation. (2008). *The San Diego Foundation Regional Focus 2050 Study: Working Papers for the 2008 Climate Change Impacts Assessment, Second Biennial Science Report to the California Climate Action Team*. Retrieved from San Diego: http://www.delmar.ca.us/DocumentCenter/View/1891

Tidwell, V. C., Dale, L., Franco, G., Averyt, K., Wei, M., Kammen, D. M., & Nelson, J. H. (2013). *Chapter 12: Energy: Supply, Demand, and Impacts.*

U.S. Army Corps of Engineers (1991). State of the Coast Report, San Diego Region. Los Angeles, CA, U.S. Army Corps of Engineers, Los Angeles District. Volume I.

U.S. Army Corps of Engineers (1991). State of the Coast Report, San Diego Region. Los Angeles, CA, U.S. Army Corps of Engineers, Los Angeles District. Volume II.

USGCRP (2016). Glossary. U. S. G. C. R. P. (USGCRP). http://www.globalchange.gov/climate-change/glossary.

USGS (2013). "Land Subsidence." Groundwater Information Pages. Accessed May 2016, from http://water.usgs.gov/ogw/subsidence.html.

USGS (2015). "California aqueduct: evaluation of groundwater conditions and land subsidence along the California Aqueduct." The California Aqueduct. Accessed May 2016. http://ca.water.usgs.gov/projects/central-valley/california-aqueduct-subsidence.html

USGS (2016-a). Coastal Storm Modeling System (CoSMoS) 3.0 Southern California. U. S. G. S. (USGS).

USGS (2016-b). "Land Subsidence." USGS Water Science School. Accessed May 2016, from http://water.usgs.gov/edu/earthgwlandsubside.html.

Yates, M. L., et al. (2009). "Equilibrium shoreline response: observational modeling." Journal of Geophysical Research 114.

Young, A. P. and S. A. Ashford (2006). "Application of airborne LIDAR for seacliff volumetric change and beach sediment contributions." Journal of Coastal Research 22(2): 307-331.

Appendix A

Asset Classes

Due to the size of the data table that describes all asset classes an on-line link is provided to download the PDF file.

https://www.dropbox.com/s/mhd0po8htq0wekz/WRRM_Asset_Index_LUT.pdf?dl=0

Appendix B

Processing Methods for SDG&E's Historical Weather Data

This appendix provides a description of the processing methods developed by Technosylva to facilitate the use of the SDG&E weather data into the Wildfire Analyst software to be used for the WRRM fire growth modeling task.

1. Extract variables of interest into new NetCDFs

Input NetCDFs have lots of variables and each file is great-sized (total size is more than 1Tb). This process generates smaller files: one file by variable and month.

2. Concatenate into one file per month

In order to group into weather-homogenous periods all the data monthly analysis has been undertaken. These periods have been considered optimum taking into account homogeneity of parameters and structure of source NetCDF data.

In this way, previous process outputs will be concatenated into one file by variable and month. Therefore, this process will generate twelve monthly files by variable.

3. Calculate required percentile for each hour of a day

By parameter and month, twenty four values of desired percentile were generated. These values represent the hour of a day corresponding to a calculated percentile date.

The main target is to describe the density function for each variable of interest. Further, each variable has been grouped by month and hour of a day, in order to:

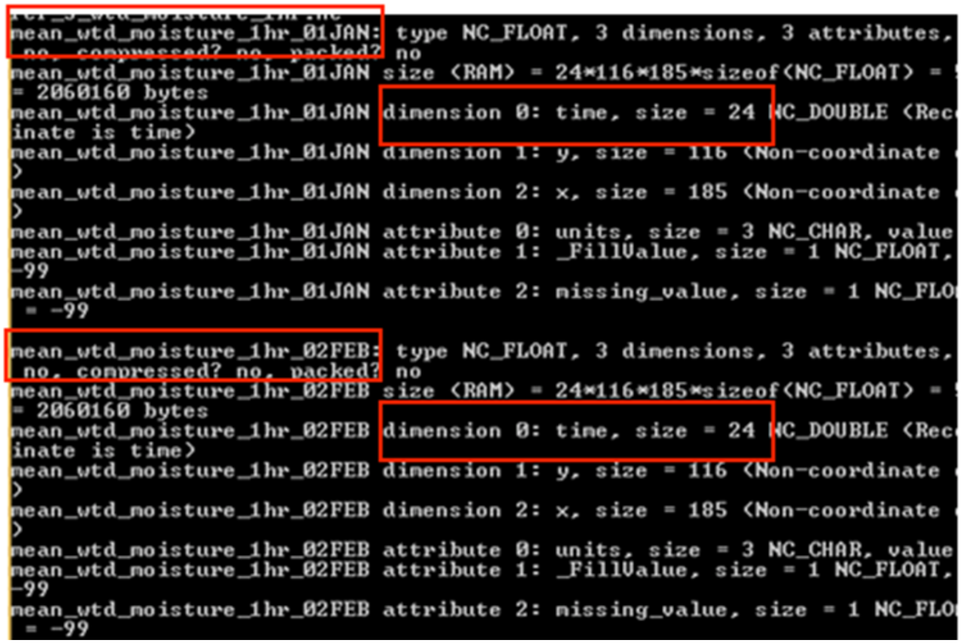
- keep weather variation in a day
- include seasonal distribution of weather scenarios

Thus, percentile selection, as shown in the example fifures was:

- 15.87; 50 ; 84.13: (corresponding to mean and standard deviation interval of a Gaussian distribution)
- 5, 15, 25, 35, 45, 55, 65, 75, 85, 95 (to explain density function)

4. Append percentiles by variable into one new NetCDF

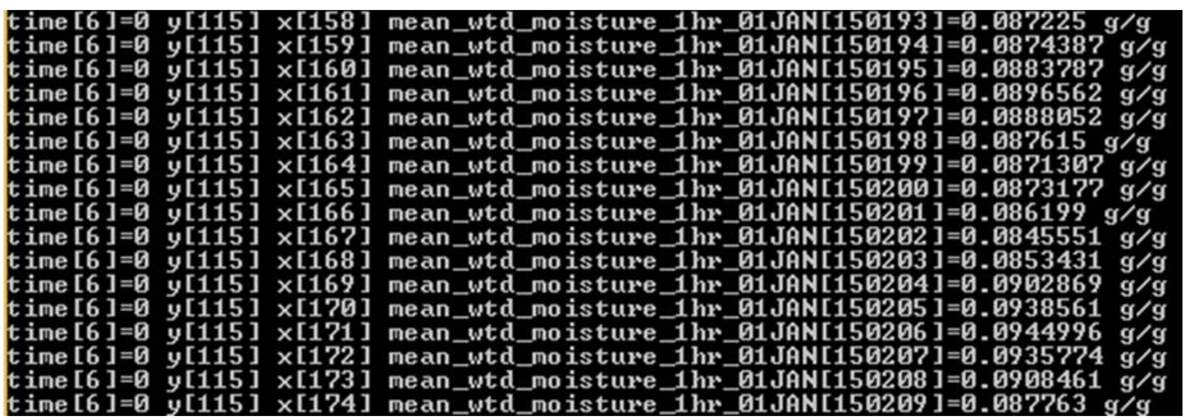
To obtain a variable NetCDF, twelve monthly files were appended. First, monthly independent variable had to be renamed ("variable" into "variable_month").



```
mean_wtd_moisture_1hr_01JAN: type NC_FLOAT, 3 dimensions, 3 attributes,
 no, compressed? no, packed? no
mean_wtd_moisture_1hr_01JAN size (RAM) = 24*116*185*sizeof(NC_FLOAT) =
= 2060160 bytes
mean_wtd_moisture_1hr_01JAN dimension 0: time, size = 24 NC_DOUBLE (Rec
inate is time)
mean_wtd_moisture_1hr_01JAN dimension 1: y, size = 116 (Non-coordinate
)
mean_wtd_moisture_1hr_01JAN dimension 2: x, size = 185 (Non-coordinate
)
mean_wtd_moisture_1hr_01JAN attribute 0: units, size = 3 NC_CHAR, value
mean_wtd_moisture_1hr_01JAN attribute 1: _FillValue, size = 1 NC_FLOAT,
-99
mean_wtd_moisture_1hr_01JAN attribute 2: missing_value, size = 1 NC_FLO
 = -99

mean_wtd_moisture_1hr_02FEB: type NC_FLOAT, 3 dimensions, 3 attributes,
 no, compressed? no, packed? no
mean_wtd_moisture_1hr_02FEB size (RAM) = 24*116*185*sizeof(NC_FLOAT) =
= 2060160 bytes
mean_wtd_moisture_1hr_02FEB dimension 0: time, size = 24 NC_DOUBLE (Rec
inate is time)
mean_wtd_moisture_1hr_02FEB dimension 1: y, size = 116 (Non-coordinate
)
mean_wtd_moisture_1hr_02FEB dimension 2: x, size = 185 (Non-coordinate
)
mean_wtd_moisture_1hr_02FEB attribute 0: units, size = 3 NC_CHAR, value
mean_wtd_moisture_1hr_02FEB attribute 1: _FillValue, size = 1 NC_FLOAT,
-99
mean_wtd_moisture_1hr_02FEB attribute 2: missing_value, size = 1 NC_FLO
 = -99
```

Figure 46. Contents of NetCDF: 12 variables (one per month) and 24 time dimensions (one per hour of a day). E.g. 1h Fuel Moisture Content



```
time[6]=0 y[115] x[158] mean_wtd_moisture_1hr_01JAN[150193]=0.087225 g/g
time[6]=0 y[115] x[159] mean_wtd_moisture_1hr_01JAN[150194]=0.0874387 g/g
time[6]=0 y[115] x[160] mean_wtd_moisture_1hr_01JAN[150195]=0.0883787 g/g
time[6]=0 y[115] x[161] mean_wtd_moisture_1hr_01JAN[150196]=0.0896562 g/g
time[6]=0 y[115] x[162] mean_wtd_moisture_1hr_01JAN[150197]=0.0888052 g/g
time[6]=0 y[115] x[163] mean_wtd_moisture_1hr_01JAN[150198]=0.087615 g/g
time[6]=0 y[115] x[164] mean_wtd_moisture_1hr_01JAN[150199]=0.0871307 g/g
time[6]=0 y[115] x[165] mean_wtd_moisture_1hr_01JAN[150200]=0.0873177 g/g
time[6]=0 y[115] x[166] mean_wtd_moisture_1hr_01JAN[150201]=0.086199 g/g
time[6]=0 y[115] x[167] mean_wtd_moisture_1hr_01JAN[150202]=0.0845551 g/g
time[6]=0 y[115] x[168] mean_wtd_moisture_1hr_01JAN[150203]=0.0853431 g/g
time[6]=0 y[115] x[169] mean_wtd_moisture_1hr_01JAN[150204]=0.0902869 g/g
time[6]=0 y[115] x[170] mean_wtd_moisture_1hr_01JAN[150205]=0.0938561 g/g
time[6]=0 y[115] x[171] mean_wtd_moisture_1hr_01JAN[150206]=0.0944996 g/g
time[6]=0 y[115] x[172] mean_wtd_moisture_1hr_01JAN[150207]=0.0935774 g/g
time[6]=0 y[115] x[173] mean_wtd_moisture_1hr_01JAN[150208]=0.0908461 g/g
time[6]=0 y[115] x[174] mean_wtd_moisture_1hr_01JAN[150209]=0.087763 g/g
```

Figure 47. Contents of NetCDF shown in figure above. Percentile 5 of 1h FMC. Time [0, 23] = 6: values of moisture by cell (x,y)

Finally, twelve monthly files were appended, so just in one single NetCDF file there is a complete explanation (temporal, spatial and statistical) of a variable. Thus, a temporal distribution can be made:

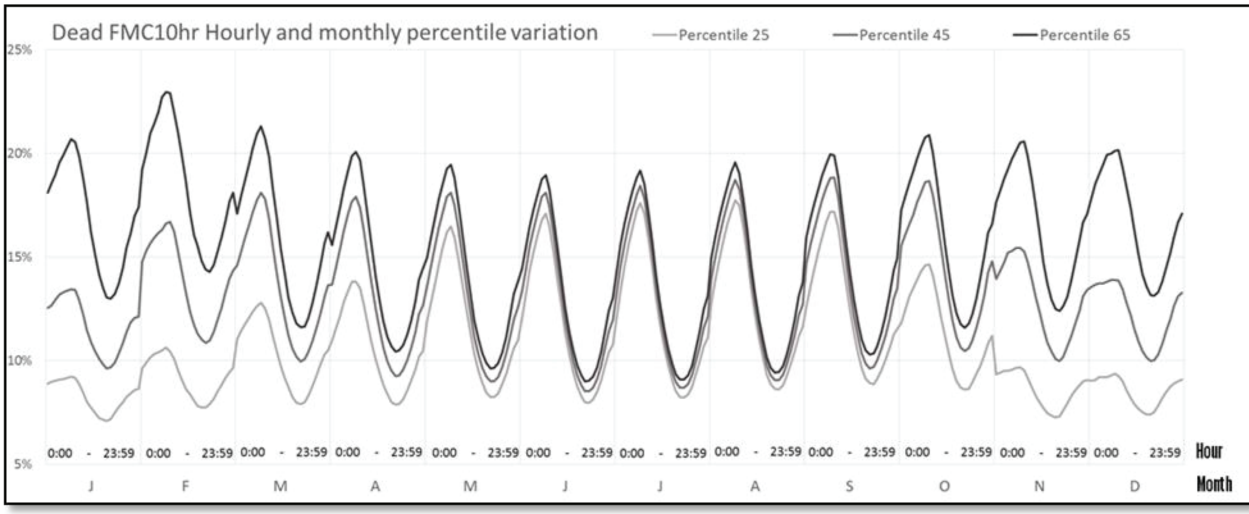


Figure 48. Temporal distribution (by month and hour of a day) for three percentiles (25, 45, 65) of 10 h Dead Fuel Moisture Content

So, resulting NetCDF (one per variable) contents are:

- Variables: One per month (12) and percentile (13): 12x13= 156 variables
- Dimensions
  - Time: 24 dimensions [0,23] day-hours
  - Coordinates (degrees): West-East / South-North

5. GIS import and behavior model input generation

These NetCDF files can be imported into GIS system (ArcGIS 10.2), to generate inputs to run fire behavior models. Next figure show an example for 10 h Dead FMC, 15th percentile in January since 00:00 to 01:00:

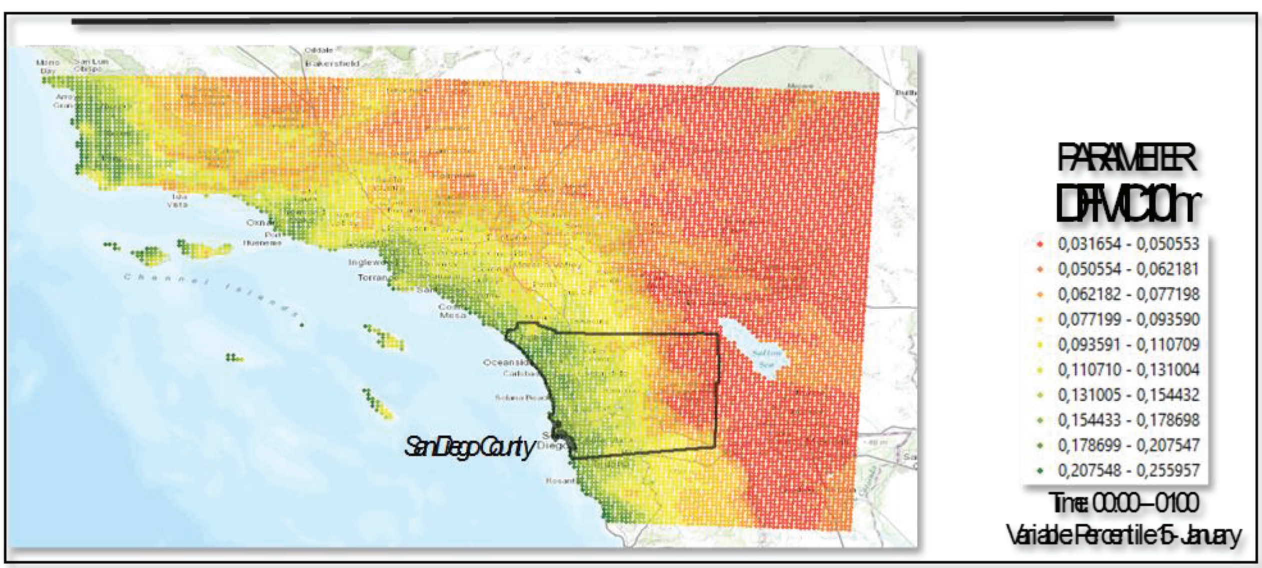


Figure 49. GIS representation of 10 h FMC: (15th percentile, January, 00:00-01:00) map

south north	west east	time	PerDens1505 01JAN	Per 15 mean wtd moisture 1hr 02FEB	Per 15 mean wtd moisture 1hr 03MAR	Per 15 mean wtd moisture 1hr 04APR	Per 15 mean wtd moisture 1hr 05MAY
32,50154	-117,1355	22	25221,38	0,150656	0,173146	0,184153	0,207585
32,50154	-117,1355	23	25221,38	0,150656	0,173146	0,184153	0,207585
34,02781	-119,879	5	25962,91	0,127091	0,153814	0,167073	0,188991
34,02781	-119,879	20	25970,22	0,152701	0,167836	0,165926	0,174139
34,00081	-119,8791	5	25982,64	0,127389	0,15011	0,164877	0,187699
34,00081	-119,8791	6	26064,1	0,123571	0,150739	0,161344	0,181747
34,00069	-119,8465	5	26096,2	0,112319	0,136003	0,156732	0,17806
33,12764	-117,3371	21	26286,93	0,147049	0,161991	0,169708	0,186434
32,11703	-116,8953	18	26317,85	0,116098	0,136804	0,14401	0,160567
33,97441	-120,1723	21	26365,72	0,163686	0,174812	0,181472	0,182538
32,11703	-116,8953	20	26449,79	0,118845	0,148889	0,168691	0,182357
33,68306	118,0311	0	26471,58	0,115176	0,141756	0,159192	0,180372

Figure 50. GIS representation of 10 h FMC: attribute table

Appendix C

Detailed Data Processing Tasks

This appendix provides a description of the detailed data processing steps identified in WRRM Model Outputs: Section D.

Ignition Points

1. Plot a network of potential ignition points that are 250 meters apart and within 250 meters of an asset.
2. Create a burnable mask.
    a. Extract urban, water, barren, desert from project area fuels
    b. Shrink urban by 1 cell
    c. Merge urban shrink with water, barren, desert to create NonBurnableMask layer
    d. Create a reverse mask to use for processing (Burnable Mask). We only want to process within the burnable areas.
3. Drop all points that are not within burnable area mask.
4. Manually QA points and drop
    a. Points that fall in water
    b. Points that are on the beach
    c. Points that are in a park surrounded by urban
5. Provide final points for modeling steps.

Impact Values

Acquire parcel and assessor data

1. San Diego County parcels acquired from SANGIS
2. Riverside County parcels acquired from Riverside County http://gis.rivcoit.org/GISData.aspx
3. Orange County parcels did not include required assessor's data. Used estimate home value data from Zillow, summarized by zip code. This is downloadable from http://www.zillow.com/research/data/

Calculate value per cell

San Diego County

1. Coordinate system is NAD_1983_StatePlane_California_VI_FIPS_0406_Feet
2. Linear Unit: Foot_US
3. Add fields (numeric, long):
    a. TotalSqFt
    b. RebuildValuePerSqFt
    c. TotalRebuildValue
    d. NumberOfCells
    e. ValuePerCell
4. Calculate TotalSqFt = Total_Lvg + Additional_A
5. Select ASR_ZONE IN (1,2,3,4)
    a. Residential Zones
    b. Calculate RebuildValuePerSqFt = 300
6. Select ASR_ZONE IN (0,5,6,7,8,9)
    a. Commercial Zones
    b. Calculate RebuildValuePerSqFt – 350
7. Select ASR_IMPR > 0
    a. Calculate TotalRebuildValue = TotalSqFt * RebuildValuePerSqFt
8. Reselect TotalSqFt = 0
    a. Calculate TotalRebuildValue – ASR_IMPR

9. Need to calculate a value per cell for parcel (total number of cells in parcel summed equals TotalRebuildValue)
    a. Ensure parcel data in a coordinate system with unit measure Foot
    b. Cell size analysis resulted in a decision to use 36 foot cells for calculations
    c. 36x36 = 1296 (area of one cell)
    d. Calculate NumberOfCells = Shape_Area / 1296
10. Select TotalRebuildValue > 0 AND NumberOfCells > 0
    a. Calculate ValuePerCell = TotalRebuildValue / NumberOfCells
11. Select ValuePerCell = 0 AND NumberOfCells > 0
    a. TotalRebuildValue was 0 in all cases
    b. Some of these are public buildings – schools, city buildings, etc. No values for asr_impr, totalsqft, etc. Cannot estimate from parcel data
    c. Reselect ASR_IMPR > 0
        i. Calculate ValuePerCell = ASR_IMPR / NumberOfCells
        ii. In some cases, this will be 0 because of very large parcels with very low value. The cost per cell is less than 0.
12. Remember: ValuePerCell * NumberOfCells will not add up exactly to TotalRebuildValue because we lose portions of cells in the raster conversion.
13. Convert parcel features to 36 foot cell size raster using ValuePerCell as grid code
14. Use Aggregate tool to convert data to 72 foot cell size for modeling

Riverside County

1. Coordinate system is NAD_1983_StatePlane_California_VI_FIPS_0406_Feet
2. Linear Unit: Foot_US
3. Add fields (Numeric, Long):
    a. TotalSqFt
    b. RebuildValuePerSqFt
    c. TotalRebuildValue
    d. NumberOfCells
    e. ValuePerCell
4. Calculate TotalSqFt = AREA_1
5. Select PRIMARY_CODE = 'R'
    a. Calculate RebuildValuePerSqFt = 300
6. Select PRIMARY_CODE IN ('C','A','P')
    a. Calculate RebuildValuePerSqFt = 350
7. Select APN = 'RW'
    a. Calculate RebuildValuePerSqFt = 0 (these are roads)
8. Select STRUCTURE > 0
    a. Calculate TotalRebuildValue = TotalSqFt * RebuildValuePerSqFt
9. Reselect TotalSqFt = 0
    a. Calculate TotalRebuildValue = STRUCTURE
10. Need to calculate a value per cell for parcel (so total number of cells in parcel summed equals TotalRebuildValue)
    a. Ensure parcel data in a coordinate system with unit measure Foot
    b. Cell size analysis resulted in a decision to use 36 foot cells for calculations
    c. 36x36 = 1296 (area of one cell)
11. Calculate NumberOfCells = Shape_Area / 1296
12. Select TotalRebuildValue > 0 AND NumberOfCells > 0
    a. Calculate ValuePerCell = TotalRebuildValue / NumberOfCells
13. Select ValuePerCell = 0 AND NumberOfCells > 0
    a. TotalRebuildValue = 0 in all cases
    b. Some of these are public buildings – schools, city buildings, etc. No values for asr_impr, totalsqft, etc. Cannot estimate from parcel data

c. Reselect STRUCTURE > 0
d. Calculate ValuePerCell = STRUCTURE / NumberOfCells
i. In some cases, this will be 0 because of very large parcels with very low value. The cost per cell is less than 0.

14. Remember: ValuePerCell * NumberOfCells won't add up exactly to TotalRebuildValue because we lose portions of cells in the raster conversion.
15. Convert features to 36 foot cell size raster using ValuePerCell as grid code.
16. Use Aggregate tool to convert data to 72 foot cell size.

Orange County

1. Download:
    a. Orange County parcels
    b. Zillow summary (current month) by zip code
        i. Using Zhvi – Zillow house value index – shows median value of estimated home values for the zip code.
    c. Zip code boundaries (used ESRI data & maps)
2. Add filed ZipString to Zillow file and calculate = RegionName
    a. Also need to add 0s to beginning of some so all are 5 digits
3. Join Zillow data to Zip code features ZipString to Zip
4. Add fields (Numeric, Long):
    a. NumberOfCells
    b. ValuePercell
5. Spatial Join zips to parcels
    a. Merge Rule on ZHVI, average
        i. If more than one zip spatially joins to 1 parcel, average the zhvi values
6. Calculate value per cell for parcel
    a. Calculate NumberOfCells = Shape_Area / 1296
    b. Calculate ValuePerCell = ZHVI / NumberOfCells
7. Select ZHVI IS NULL
    a. There are some missing areas that weren't included in the Zillow zip data
        i. Newport Coast
        ii. Parts of Newport Beach
        iii. Area NE of Irvine Lake
    b. Calculate ValuePerCell = 0
8. Convert features to 36 foot cell size raster using ValuePerCell as gridcode
9. Use Aggregate tool to convert data to 72 foot cell size
10. Filter out areas with value < 1000 – try to eliminate large areas where there are no structures. Parcels have value, but we're only interested in value of structures.
    a. Used 1000-10,000 looked good on the outskirts, but lost some densely populated areas. Did some spot checks and we'd lose houses by going above 1,000.
11. Coordinate System is NAD_1983_StatePlane_Califonria_VI_FIPS_0406_Feet
12. Linear Unit: Foot_US

Merge counties

1. After all county parcel data sets have been calculated for ValuePerCell and converted to raster, merge all counties together to create one seamless raster across the project area.
2. Output raster = SDGE_ValuePerCell

Apply percent loss

1. After looking at various methods to calculate a percent loss using parcel age and building codes, a decision was made to apply a percent loss value based on geographic area. SDG&E provided polygons and expected percent loss within each polygon. These were used to calculate Adjusted Loss by cell.
2. Calculate % loss on 72 foot cell merged raster

    a. Tier 1 20% structure loss
    b. Tier 2,3 15% structure loss
    c. Tier 4 5% structure loss
3. Add field PercentLoss (float) to OIR Tiers
    a. Calculate according to values provided above (20% = 0.20)
4. Convert OIR to raster, match cell size and snap to merged output (SDGE_ValuePerCell)
    a. Use PercentLoss field as output raster field
5. Use Map Algebra
    a. OIRRaster * SDGE_ValuePerCell
6. Output raster = SDGE_AdjustedValuePerCell
7. Provide output for modeling steps

Prepare Asset Data

When writing up methods for asset data, remember to change asset index to be 6 digits – we dropped windy from conductors and dropped every asset 1 digit

1. Create a new file geodatabase
2. Open ArcMap document and load:
    a. Overhead Structure
    b. Dynamic Protective Device
    c. Fuse
    d. PF Correcting Equipment
    e. Pri OH Conductor
    f. Transformer Device
3. Set Definition Queries:
    a. Overhead Structure
        i. SUBTYPECD < 3
    b. Dynamic Protective Device
        i. OHUG = 'OH'
    c. Fuse
        i. OHUG = 'OH'
    d. PF Correcting Equipment
        i. OHUG = 'OH'
    e. Transformer Device
        i. OHUG = 'OH'
4. Open Attribute tables, add WRRMID field and calculate:
    a. Overhead Structure
        i. Add: WRRMID, string, 255
        ii. Calc WRRMID = [GLOBALID]
    b. Fuse
        i. Add: WRRMID, string, 255
        ii. Calc WRRMID = [GLOBALID]
    c. PF Correcting Equipment
        i. Add: WRRMID, string, 255
        ii. Calc WRRMID = [GLOBALID]
    d. Pri OH Conductor
        i. Add: WRRMID, string, 255
        ii. Calc WRRMID = [GLOBALID]
    e. Transformer Device
        i. Add: WRRMID, string, 255
        ii. Calc WRRMID = [GLOBALID]

5. Export the following feature classes to new file geodatabase, with definition query (do not change coordinate system)
    a. DynamicProtectiveDevice as DynamicProtectiveDeviceOH
    b. Fuse as FuseOH
    c. PFCorrectingEquipment as PFCorrectingEquipmentOH
    d. PriOHConductor as PriOHConductor
    e. OverheadStructure as OverheadStructureDistribution
    f. TransformerDevice as TransformerDeviceOH
6. Export the following tables to new file geodatabase
    a. CapacitorUnit
    b. FuseUnit
    c. PriOHConductorInfo
    d. StructureUnit
    e. TransformerUnit
7. Open table, add field, and calculate
    a. CapacitorUnit
        i. Add WRRMID, text, 255
        ii. Calculate WRRMID = [CAPACITORBANKGUID]
    b. FuseUnit
        i. Add WRRMID, text, 255
        ii. Calculate WRRMID = [FUSEGUID]
    c. PriOHConductorInfo
        i. Add WRRMID, text, 255
        ii. Calculate WRRMID = [PRIOHCONDGUID]
        iii. Add DSS, short, (Dynamic, Similar, Single)
        iv. Calculate in next step…
    d. StructureUnit
        i. Add WRRMID, text, 255
        ii. Calculate WRRMID = [STRUCTUREGUID]
    e. TransformerUnit
        i. Add WRRMID, text 255
        ii. Calculate WRRMID = [TRANSFORMERGUID]
8. Calculate DSS in PriOHConductorInfo
    a. Need to determine which conductors have single spans, multiple similar spans, or multiple dissimilar spans.
    b. Set up relate between PriOHConductor and PriOHConductorInfo
        i. PriOHConductor WRRMID
        ii. PriOHConductorInfo WRRMID
    c. In Info, Select PHASEDESIGNATION = 8
    d. Relate to PriOHConductor
    e. Relate to PriOHCondcutorInfo
    f. Switch Selection
    g. Calculate DSS = 30 (Single)
    h. Select DSS IS NULL
    i. ReSelect for each Size/Type/Material/age

For example: ((CONDUCTORSIZE = '#6' OR CONDUCTORSIZE = '6') AND CONDUCTORTYPE = 'B.STRD' AND CONDUCTORMATERIAL = 'CU') AND WODate <= date '1964-12-31 00:00:00'

    j. Relate to PriOHConductor
    k. Relate back to PriOHConductorInfo
        i. These are spans with multiple lines
        ii. Calc DSS = 20

l. Deselect selection criteria
m. Relate to PriOHConductor
n. Relate back to PriOHConductorInfo
    i. These are spans with dissimilar lines
    ii. Calc DSS = 10

9. Run Select Related Records tool (in ArcMap)
    a. NOTE: This step takes significant processing time. ~60 hours for all
    b. PF Correcting Equipment OH
        i. PFCorrectingEquipmentOH
        ii. WRRMID
        iii. CapacitorUnit
        iv. WRRMID
        v. NO SQL
        vi. Export Selected Features
        vii. PFCorrectingEquipmentOHflat
    c. FuseOH
        i. FuseOH
        ii. WRRMID
        iii. FuseUnit
        iv. WRRMID
        v. NO SQL
        vi. Export Selected Features
        vii. FuseOHflat
    d. Transformer Device OH
        i. TransformerDeviceOH
        ii. WRRMID
        iii. TransformerUnit
        iv. WRRMID
        v. NO SQL
        vi. Export Selected Features
        vii. TransformerDeviceOHflat
    e. Pri OH Conductor
        i. PriOHConductor
        ii. WRRMID
        iii. PriOHConductorInfo
        iv. WRRMID
        v. NO SQL
        vi. Export Selected Features
        vii. PriOHConductorflat
    f. Overhead Structure
        i. OverheadStructureDistribution
        ii. WRRMID
        iii. StructureUnit
        iv. WRRMID
        v. NO SQL
        vi. Export Selected Features
        vii. OverheadStructureDistributionflat
    g. Dynamic Protective Device OH does not have a related table and does not need to be
        i. processed
10. Reproject to UTM 11 nad 83 meters – change names
    a. DPD
    b. Fuse
    c. Poles

    d. Capacitor
    e. Transformer
    f. Conductor
11. Add ASSETINDEX field (long) and A1-A6 fields to all feature classes and calculate according to LUT
    a. Remember, when you flatten and you add a field with the same field name as the main fc, the new one has _1 appended. This is important to know for QC later.
    b. Apply domains to A1-A6, calculate these first and use them to calculate final ASSETINDEX field

Wind Factor Calculation

1. For each asset in the system, we added an attribute called WindFactor. This is attributed from the SDG&E provided FireWindGustPolygons and a look up table. There are 2 WindFactor datasets – one for poles & conductors, and one for everything else.
2. Import FireWindGustPolygons and Reproject to working coordinate system
3. Add field WindFactor to each asset feature class
4. Run a spatial join on each asset feature class with FireWindGustPolygons
5. Drop all new fields except Name and GustSpd
6. Calculate WindFactor according to look up table

WindFactor Look Up Table 10/16/2015		
Gust wind speed (mi/h)	POLES/ CONDUCTORS	ALL OTHER ASSETS
0-55	0.10	0.40
55-65	0.20	0.50
65-75	0.35	0.60
75-85	0.50	0.70
85-95	0.65	0.80
95-105	0.85	0.90
105-111	1.00	1.00

Final Asset Calculations

1. Get Impact points from Modeling (Ignition points after modeling)
    a. Run Impact IDW for poles/conductors
        i. Output cell size 20
        ii. Power 2
        iii. Search radius variable
        iv. Number of points 5
        v. Maximum distance 300
    b. Run Impact IDW for other assets
        i. Output cell size 20
        ii. Power 2
        iii. Search radius variable
        iv. Number of points 5
        v. Maximum distance 300
2. Change Null values in IDW outputs to 0
3. Add required fields
    a. ReplacementAsset
    b. cCon
    c. CurrentFailRate
    d. IgnitionRatio

    e. ReplacementFailRate
    f. CurrentIgnitionRate
    g. eCon
    h. ReplacementIgnitionRate
    i. ReplacementECon
    j. RiskReduction
4. Process against raster outputs (ensure both are in same coord sys)
    a. Conductors
        i. Use IDW calculated with Poles/Conductors values
        ii. Use geospatial modeling environment and R to get a length weighted mean for each line segment
        iii. Need to run as shapefile and grid
            1. Export conductors to shapefile
            2. Export rasters to grids
        iv. Use isectlinerst
            1. Input Conductor shape
            2. Input grid
            3. Prefix mny
            4. Leave everything else as default
            5. Run
        v. Drop unneeded fields (*min, max, beg, end)
        vi. Join and calculate back to feature class using WRRMIDs
            1. Remember to start an edit session before calculating – otherwise it will take 7 hours.
    b. Extract Values to Points for all other assets
        i. For poles, use IDW created using Poles/Conductors values
        ii. For all other assets, use IDW created using Other values
        iii. Spatial Analyst Tools > Extraction > Extract Values to Points
        iv. Save as *_money
    c. Review outputs
5. Reproject to web Mercator and save final back to base name
6. Join to Asset Index LUT
    a. Join Asset Class / Asset Index to calculate values
7. Calculate remaining fields

Field	**Calculation**
ReplacementAsset	From AssetLUT
CurrentFailRate	From AssetLUT
IgnitionRatio	From AssetLUT
ReplacementFailRate	From AssetLUT
CurrentIgnitionRate	CurrentFailRate * IgnitionRatio * WindFactor
eCon	cCon * CurrentIgnitionRate
ReplacementIgnitionRate	ReplacementFailRate * IgnitionRatio * WindFactor
ReplacementECon	cCon * ReplacementIgnitionRate
RiskReduction	cCon*((1-(1-(CurrentIgnitionRate))^PlanningHorizon)-(1-(1-(ReplacementIgntionRate))^PlanningHorizon))

Appendix D

Interview Questions

Utility Practitioner:

1. We have a copy of your vulnerability assessment to climate change & extreme weather. We have reviewed this & would like to ask the following specific questions.
    - 1a. What were the key vulnerabilities you identified and why?
    - 1b. What were the specific climate change drivers you identified (e.g., SLR)?
    - 1c. Do you use asset-specific thresholds to evaluate vulnerability? If so, what are these?
    - 1d. How do you define 'critical infrastructure' in your assessment?
    - 1e. Are there updated or new adaptation/resiliency policies as a result of your assessment?
2. Do you have any specific climate change adaptation or resiliency building measures planned or currently being implemented that were flagged in your vulnerability assessment? If so, what?
    - 2a. What adaptation or resiliency measures are planned be incorporated during asset lifecycles, vs specific new investments?
3. Are there co-benefits that you considered in the prioritization of your adaptation/resiliency investments (e.g., lower cost, market access, higher reliability)?
4. What are your key barriers for adapting to climate change or increasingly resiliency right now?
5. What policies or regulations do you think are needed (or removed) to help your climate change and resiliency enhancement measures?)
6. Is there anyone else you recommend we talk to?
7. Anything else you'd like to add

Regional Expert

1. Can you tell me about previous assessments in which you've been involved with in the San Diego region, and provide us with a background to both the work and your specific involvement in them? We are interested in understanding the specific climate change scenarios that you used to do your assessment.
    - i. Imperial Beach – Principal Investigator - Using Cosmos (combined preliminary 3.0 with 1.0) and SPAWAR mash up.
    - ii. Carlsbad – Technical advisor to Moffat and Nichol – Using preliminary Cosmos 3.0.
    - iii. NOAA coastal resilience.
2. Which sources of data did you use to do your hazard assessment?
3. If you were to do this again, what scenarios would you use and why?
4. Can you share these scenarios?
5. Do you have any draft or in press publications that you would be able to share with us?
6. What projects are you involved with that will provide results over the period of our Study (mid-2017)?

Support for SDG&E Climate Adaptation: Flexible Sea Level Rise Adaptation Pathway for Montgomery Substation

February 28, 2019

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Table of Contents

I. Introduction

In recent years, San Diego Gas and Electric (SDG&E) has taken substantial steps to analyze and begin mitigating potential future impacts of climate change on its operations. From 2016 to 2018, SDG&E partnered with ICF on a study, funded by the California Energy Commission (CEC) and published in the California Fourth Climate Assessment, to assess vulnerabilities to its electric system assets from sea level rise.[1] One priority asset with potential vulnerabilities that ICF's research identified was the Montgomery Substation. Since the publication of the CEC-funded analysis, SDG&E has been working with ICF to explore the potential of *flexible adaptation pathways* as a strategy for mitigating these and other climate risks.

This report details ICF's additional findings on specific vulnerabilities of the Montgomery Substation to sea level rise, and presents a draft flexible adaptation pathway for mitigating these vulnerabilities. These results are the product of ICF research, on-the-ground and GIS-based site surveys, and targeted discussion with SDG&E staff. The aim is to provide a framework for the development of a detailed flexible adaptation pathway for the Montgomery Substation, ultimately to be informed by a detailed technical and cost-benefit analysis

1. Background on Flexible Adaptation Pathways

Flexible adaptation pathways provide a framework for managing climate change risks that optimizes long-term planning in a way that accounts for uncertainty. ICF's prior study of climate risks to SDG&E assets provided the following explanation of the flexible adaptation pathways approach and its motivations:

> *"Flexible Adaptation Pathways are an approach to adaptation that allows for decision makers to adjust to new information and circumstances over time. This approach allows the decision maker to manage the uncertainty of the future, rather than getting locked into adaptation measures made in anticipation of potential impacts that may not occur or in ignorance of unforeseen impacts. The pathways include immediate adaptation actions that could be taken today, and other adaptation actions that could be taken as new information becomes available and certain thresholds are met."*[2]

Under a flexible adaptation pathways framework, *indicators* represent the climate-relevant information that is being monitored. *Thresholds* represent specific conditions of indicators that prompt adaptation decisions or actions. As an example, average annual sea level might be an indicator, and an increase of 0.5 meters in annual mean sea level might be a threshold that prompts preparation for action. This report explores these concepts in greater detail and with specific application to the Montgomery Substation. Figure 2 and Figure 3, presented later in this report, provide a pictorial summary of the proposed pathway framework for Montgomery Substation.

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[1] Bruzgul, Judsen, Robert Kay, Andy Petrow, Tommy Hendrickson, Beth Rodehorst, David Revell, Maya Bruguera, Dan Moreno, Ken Collison. (ICF and Revell Coastal). 2018. Rising Seas and Electricity Infrastructure: Potential Impacts and Adaptation Actions for San Diego Gas & Electric. California's Fourth Climate Change Assessment, California Energy Commission. Publication Number: CCCA4-CEC- 2018-004, http://www.climateassessment.ca.gov/techreports/docs/20180827-Energy_CCCA4-CEC-2018-004.pdf.

[2] Ibid.

II. Sea Level Rise Exposure and Vulnerability Assessment for Montgomery Substation

As an initial step in developing a flexible adaptation pathway, ICF conducted a detailed analysis to determine potential exposure to sea level rise and specific points of vulnerability within the substation. This process consisted of a site visit and a GIS survey, and subsequent discussion of the results with SDG&E subject matter experts.

1. Site Visit and GIS Survey

To provide a detailed understanding of sea level rise risk to Montgomery substation, ICF conducted a site visit and prepared a GIS mapping analysis. The results of the GIS analysis are included as an appendix to this report, and both the photos and the GIS analysis are included in the separate Site Survey Report (delivered under separate cover for purposes of streamlining). The site visit produced a set of photographs documenting potentially vulnerable equipment at the substation, as well as relevant features of the surrounding area. The GIS analysis produced maps modeling the depth and duration of flooding at Montgomery substation under average conditions and 100-year flood events, assuming various levels of future potential sea level rise.

Figure 1 shows a sample map, illustrating flood depth at the substation during a 100-year flood event under 1.5 meters of sea level rise, with the substation outlined by the black dotted line.

Figure 1: USGS-Modeled Flood Exposure of Montgomery Substation During 100-Year Flood Event Under 1.5 Meters of Sea Level Rise (note: Substation outlined shown as a dashed-line square. Yellow, orange and red lines refer to the site visit protocol – see Appendix)

Source: ICF Analysis of USGS data

Notably, the baseline conditions in the United States Geological Survey (USGS) mapping represent the substation site as being a flood prone low-lying area, even in the absence of future sea level rise. However, this likely reflects an error in USGS data that may overrepresent risk. ICF's analysis detected an anomaly in USGS inundation data, which results in corruption of part of the flood mapping of the Montgomery substation area. ICF confirmed with USGS that the detected anomaly represents a data error. USGS staff indicated that the error cannot be immediately corrected within their dataset. Consequently ICF, recommends additional inundation analysis as a future step to produce improved mapping of present and future risk.

2. Potential Vulnerabilities Identified

ICF reviewed and analyzed the products of the above survey in a series of working sessions with SDG&E substation engineering, distribution planning, and climate adaptation staff. The dialogue identified several assets potentially sensitive to flooding at the Montgomery substation, subject to further study by SDG&E. These include:

- Below grade cables (power conductors, control circuits, and grounding)
- Breakers
- Control boxes
- Transformers
- Capacitor bank isolators

The presence of sensitive below-grade equipment indicates current vulnerability to flooding of any level as water would percolate below ground. Other assets, positioned at different heights, represent additional relevant thresholds of sensitivity to flooding. In addition, discussion with SDG&E staff, and subsequent research prompted by these discussions, indicated potential for corrosion damage to substation grounding equipment as a result of the presence of increased saline groundwater associated with sea level rise.

Flooding damage at the substation could result in the following consequences for SDG&E:

- Health and safety risks associated with substation flooding
- Fire risks if operational measures cannot de-energize transformers during rapid flooding
- Loss of service to customers in service territory (including major industrial customers)
- Disrupted operation and delayed access to control shelters

III. Adaptation Measures and Flexible Adaptation Pathway Framework

1. Potential Adaptation Measures

ICF conducted a survey of relevant literature, with support from SDG&E engineering staff, which produced the following list of potential adaptation measures for substations exposed to sea level rise.[3] These potential measures were shared with SDG&E staff as part of the pathway development process.

- Enhance communications and remote monitoring to enhance situational awareness
- Build levees or flood gates
- Enhance grid interconnections to provide redundancy in power supply to customers
- Use waterproof/seawater-tolerant equipment
- Elevate critical equipment
- Elevate entire substation
- Install drainage pumps
- Purchase/reserve new potential substation site (as hedge for potential relocation)
- Relocate substation

2. Flexible Adaptation Pathway Framework

Based on assessment of exposure and adaptation options and with initial feedback from SDG&E staff, ICF developed a framework for a flexible adaptation pathway to address sea level rise related hazards. For clarity of presentation, this report depicts the pathway in two separate figures: Figure 2 depicts a pathway to monitor and address flood risk, and Figure 3 depicts a pathway associated with groundwater salinity risk.

These pathways are presented as an initial framework, and a basis for detailed engineering and economic analysis to evaluate the efficacy, appropriate monitoring thresholds, and appropriate sequencing of the measures introduced here. The final pathway implemented may differ from these depictions based on the conclusions of SDG&E's in-depth analysis.

In the pathway diagrams, colored horizontal lines represent courses of action that could be taken along an adaptation pathway. The solid lines represent the initial preferred pathway sequencing based on current understanding, whereas the dotted lines represent alternative sequencings. Many of these lines reach "terminal points," indicated by short vertical bars, at which the adaptation is no longer useful given the extent of hazard exposure. The termination of the "current policy" line indicates the point at which adaptation measures are needed. White circles represent "triggers," points at which information produced by a monitoring action (informed by analysis) dictates an adaptation response.

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[3] J.W. Baker, "Eliminating Hurricane-Induced Storm Surge Damage to Electric Utilities via In-Place Elevation of Substation Structures and Equipment," IEEE Conference Paper, 2014; J.M Boggess, "Storm & Flood Hardening of Electrical Substations" IEEE Conference Paper, 2014; U.S Department of Energy, "Risk Assessment for Storm Hardening: Technical Workshop on Resilience Metrics," 2014.

Figure 2: Flexible Adaptation Pathway for Flood Inundation Risk to Montgomery Substation

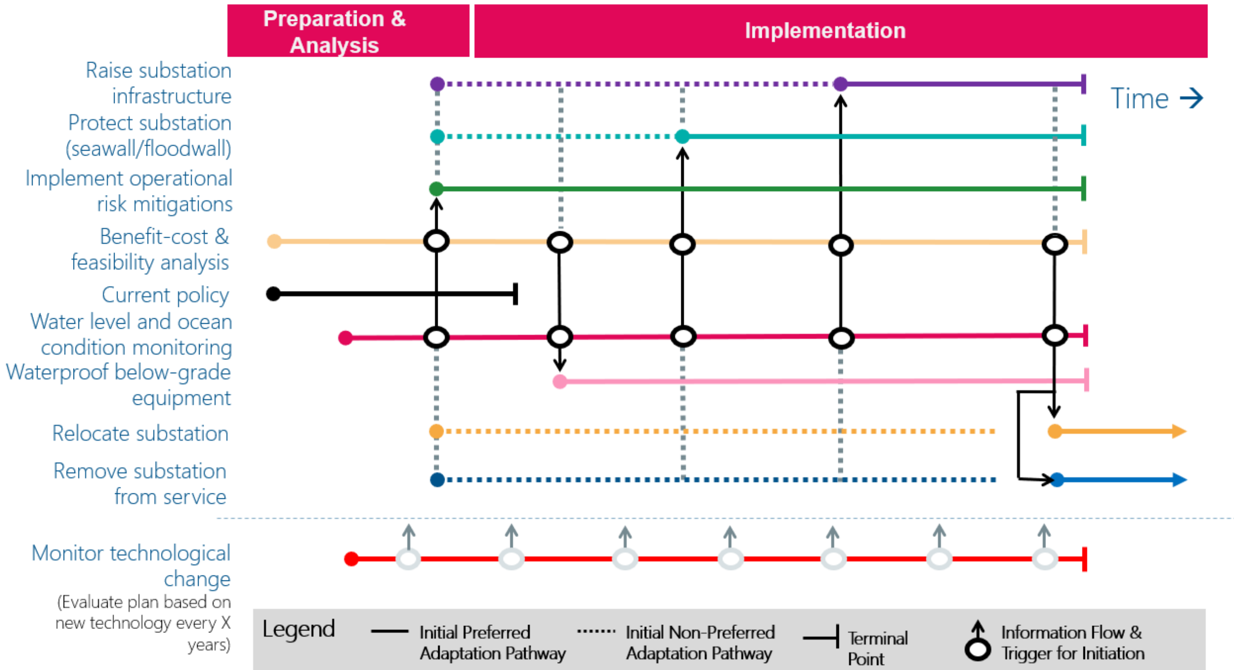
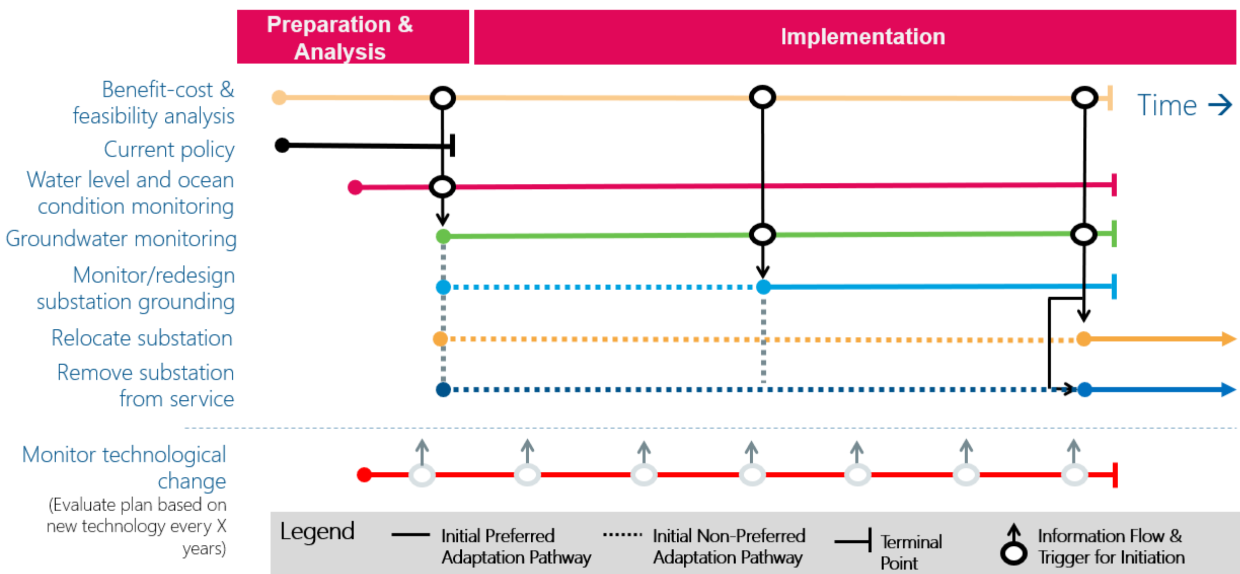


Figure 3: Flexible Adaptation Pathway for Saline Groundwater Risk to Montgomery Substation



For example, flood risk monitoring might use a change in mean sea level as an indicator for change (indicators are further discussed in section 2.1.3). When the indicator reaches a key threshold (or “trigger” point), the asset manager should plan to take adaptation action. In the diagrams, black arrows connect trigger points to the associated adaptation actions. The diagrams do not present specific units of time, as timing of adaptation actions will depend on the progression of water conditions.

2.1.1 Preparation & Analysis Phase

The first phase of the flexible adaptation pathway process is to conduct preparatory activities and additional analysis to determine the optimal pathway indicated by the best currently available information. This report represents the start of that phase. As the diagrams show, benefit-cost and feasibility analysis extend throughout the implementation of the flexible adaptation pathway.

The initial analysis phase should continue to address the following questions:

- What is the maximum acceptable level of risk to this asset, and how is that risk defined? (E.g. safety impacts, customer outage impacts, financial loss)
- What adaptation options are available, and to what degree do each of the measures reduce risk?
- What threshold levels of the indicators being monitored represent trigger points for action.
- What are the relative costs of these adaptation measures at various levels of hazard severity?
- What combination of measures produces the overall lowest-cost pathway to acceptable risk under a range of potential hazard scenarios?
- To what degree are adaptation measures flexible?
- Can a specific measure be reversed? Can it be increased in scope later? (E.g., can additional height be easily added to a seawall at a later date?)
- How robust are adaptation measures to different climate scenarios and other future uncertainties?
- What are the prerequisites to implementing a measure? (E.g., permits required)
- How long does an adaptation measure take to plan for, design and implement?
- Which measures can be pursued in tandem, and which measures represent divergent pathways? (E.g., raising equipment and building a seawall can be pursued in tandem, but are not complementary with relocating the substation entirely)
- Are there any limitations to the effectiveness or feasibility of specific adaptation measures? (E.g. a transformer cannot be elevated above a certain height due to the presence of overhead equipment that would be costly to move).

The answers to these questions will confirm the structure of the initial pathway. Benefit-cost and feasibility analysis should continue over time as new information becomes available. Conducting thorough and comprehensive analysis before the implementation phase is of critical importance to designing the optimal pathway, as it is likely to reveal information that determines the optimal and least-cost sequence of adaptation measures.

2.1.2 Adaptation Actions

As shown in the adaptation pathway diagram above for flood risk (Figure 2, above) changing water levels trigger the following sequence of actions at progressively higher water levels:

1) Implement operational risk mitigations (E.g. develop procedures for substation de-energization/switching in the event of flood; plans for floodwater pumping)
2) Waterproof below-grade equipment (E.g. exchange metal control cables for fiber-optic cables)
3) Protect substation with seawall or floodwall
4) Elevate substation infrastructure
5) Relocate substation OR remove substation from service

The pathway framework indicates that water levels reaching a certain height would trigger the installation of groundwater monitoring equipment to address groundwater salinity risks via the adaptation pathway mapped in Figure 3. Changing saline groundwater conditions trigger the following sequence of actions at progressively higher groundwater levels:

1) Monitor/redesign substation grounding
2) Relocate substation or remove substation from service

While the draft adaptation pathway represents a simplified overview of the actions, each action may actually consist of multiple incremental actions, triggered by different monitoring thresholds. For example, flood barriers may be built incrementally higher as different water level thresholds are reached. Similarly, an initial groundwater salinity threshold may trigger more frequent monitoring of grounding equipment, while a higher threshold may trigger a redesign of the equipment.

Additionally, benefit-cost analysis and feasibility will likely change the final form of this pathway. Analysis may show that elevating substation equipment is too costly, and that progressing directly to substation relocation or removal from service is the preferable option. Similarly, analysis will be required to determine whether it is preferable as a last resort to relocate the substation or to remove it from service and resupply its distribution area from other substations.

2.1.3 Monitoring Strategy

Monitoring of change in water level and groundwater conditions is the foundation of effectively implementing the adaptation pathways, and is the first action that must be taken. This section presents additional detail on the design of an effective monitoring strategy.

Monitoring changes in water levels may consist of monitoring tide gauge readings, flood events at the substation, or a combination thereof. SDG&E is already pursuing the construction of a Montgomery tide gauge with Scripps, and may also consider other measures, such as float switches, located within the substation, to detect inundation events. As indicated in the adaptation pathway diagrams, changes in water levels will trigger subsequent adaptation actions at defined trigger points, informed by benefit-cost and feasibility analysis. Similarly, monitoring changes in groundwater salinity will provide information about when to pursue measures related to protecting substation grounding.

ICF conducted an initial survey of available equipment that may be suitable for detecting changes in water levels and groundwater conditions that can be placed within the substation perimeter Montgomery substation (in addition to the new Montgomery tide gauge). This monitoring equipment includes:

- Float switches to detect inundation
- Rope-style water sensors
- Soil conductivity meters, to detect changes in soil salinity
- "Pre-packed" monitor wells for obtaining groundwater samples and monitoring groundwater levels

Installation and operational integration of monitoring equipment allows for the monitoring of key physical indicators for change. Table 1 provides a list of potential indicators that could be associated with trigger points in a fully-developed flexible adaptation pathway for the Montgomery Substation. Note that some indicators (marked with asterisks) represent important operational, regulatory, and societal indicators that serve as secondary "checks" on the adaptation pathway, but are not explicitly included in the pathway maps above. The monitoring of environmental conditions represents the core of the pathway plan, but these other factors remain important reactive signals for potential reanalysis and revision.

Table 1: Potential Indicator Values for Montgomery Substation Flexible Adaptation Pathway

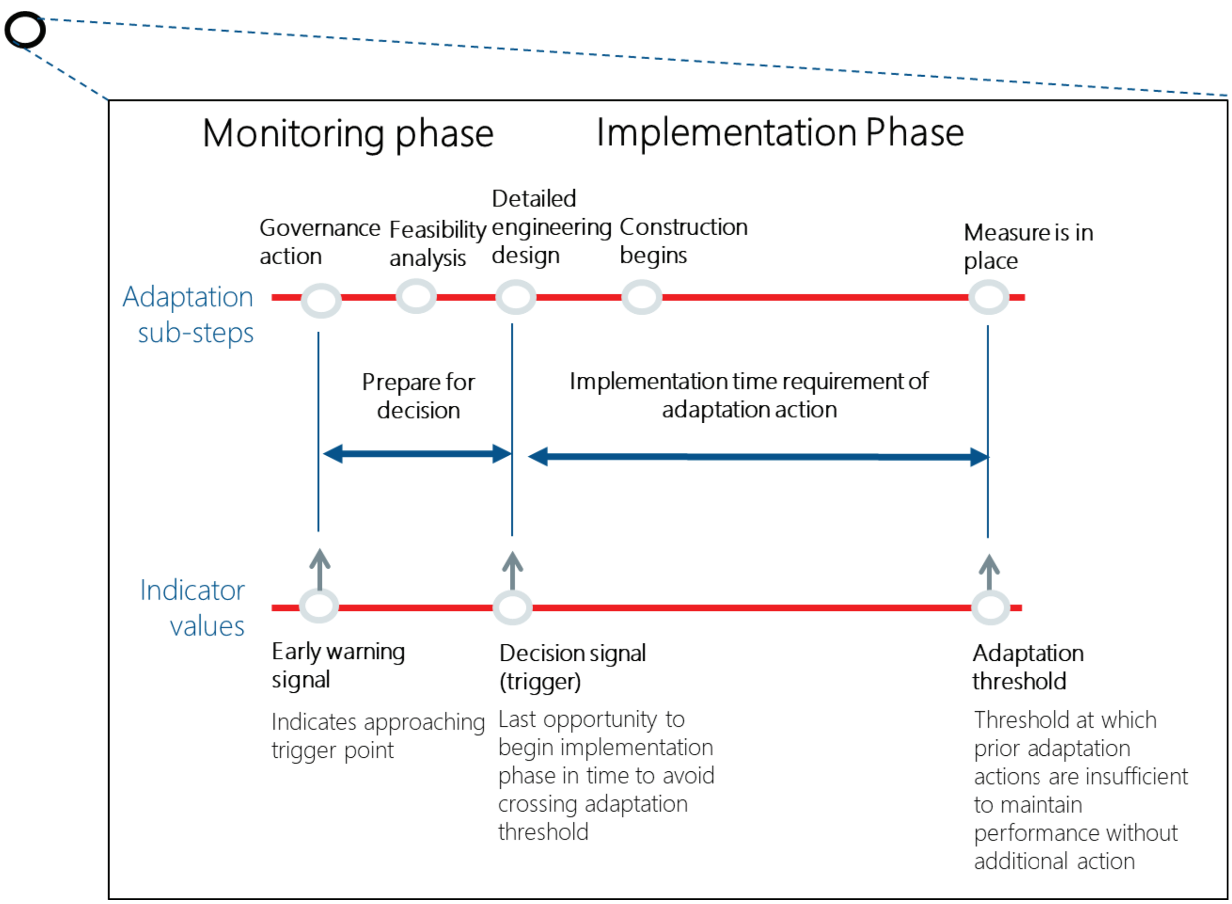
Hazard	Indicator	Monitoring Method
Flood Risk	Long-term sea level conditions (Mean Sea Level / Mean Higher High Water)	Montgomery tide gauge
	Change of extreme values (at tide gauge)	Montgomery tide gauge
	Recorded floodwater in substation	Float switches within substation
	Operational disruption*	Substation incident reporting
	State regulatory requirement for flood risk protection of critical assets*	Tracking of regulatory proceedings
	Local (city/county/precinct) coastal plan or sea level rules*	Tracking of local plans and ordinances
	Customer concern*	Correspondence received
Corrosion Risk from Saline Groundwater	Long-term sea level conditions (e.g. Annual Mean Sea Level / Annual Mean High-High Water)	Montgomery tide gauge
	Peak annual groundwater depth	Pre-packed wells installed at substation
	Mean annual groundwater depth	Pre-packed wells installed at substation

Further development of a monitoring strategy based on indicators such as the above will be central to the additional development of a detailed adaptation pathway. In particular, effort should focus on the establishment of specific quantitative thresholds associated with adaptation trigger points. Determining these values enables the core value of the pathway approach.

Figure 4 provides a more detailed view of the actions that occur when the monitoring of a certain enironmental pararamter, such as sea-level rise recorded by a tide gauge, reaches a trigger point. This figure shows a “zoomed in” view of one of the trigger points represented by the black-outlined circles in Figures 2 and 3. Because many adaptation actions take several years to implement, an adaptation pathway should identify a series of monitoring ‘indicator values’, shown on the bottom line of Figure 4. These indicator values initiate a series of action sub-steps, shown on the upper line in the figure. The first relevant indicator value is an early warning signal, designed to indicate an approaching decision signal, or “trigger” moment.

Following the early warning signal, Figure 4 represents actions that could be taken by SDG&E asset managers to initiate governance actions required to move toward asset construction, such as escalating internally within the company to obtain budget and approvals. Subject to the cost and complexity of the required action, there may be a need for governance actions to notify regulators and/or incorporate investments plans into a general rate case request. SDG&E would then proceed with a feasibility analysis, and would be prepared to begin detailed design planning and construction by the time the indicator value reaches the decision signal, or trigger, determined based on an estimate of the last moment to safely act.

Figure 4: Detailed Decomposition of a Trigger Point



Source: ICF adaptation of Haasnoot et al. 2018[4]

[4] Haasnoot, Marjolijn, Susan van’t Klooster, and Jos van Alphen. "Designing a monitoring system to detect signals to adapt to uncertain climate change." Global Environmental Change 52 (2018): 273-285.

2.1.4 Monitoring Technological Change

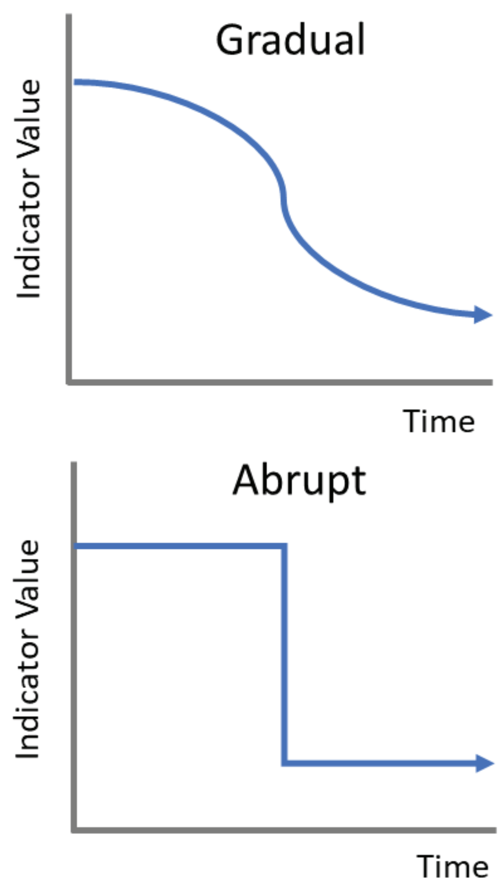
A separate but critical element of the flexible adaptation pathway approach is the continual revision of the pathway based on new technology. Re-evaluation of the pathway based on state-of-the-art substation and climate adaptation technology should occur at fixed intervals (e.g. every 5 years).

3. Further Application of Flexible Adaptation Pathways to SDG&E Assets

ICF's work towards the development of a detailed flexible adaptation pathway for the Montgomery substation and discussion with SDG&E staff produced the following insights applicable to the Montgomery substation and other SDG&E assets:

- Technical and engineering staff responsible for substation engineering and distribution planning showed a high level of engagement. Staff attended project meetings where the pathways approach was discussed, and provided technical publications from industry journals and other relevant sources. This suggests that the next step in developing a detailed pathway based around the Montgomery substation concept can be undertaken through a process that engages these staff and other relevant team members from across SDG&E.
- The development of detailed indicator threshold values is highly site and equipment-specific, and will require significant engagement from engineering and distribution planning staff.
- The development of a detailed adaptation pathways plan requires both up-front and ongoing cost and technical feasibility analysis. Determination of an initial set of appropriate adaptation actions and their sequencing requires an initial analysis, and additional analysis over the course of implementation will also be required in the face of changing environmental conditions, grid conditions, and technology.
- The relevance of performance-based indicators (such as those which might be derived from the outage analysis ICF conducted in an earlier phase of work with SDG&E) within an adaptation pathway varies by asset. In the example of flood risk to a substation, impacts of exposure on performance are likely to be abrupt and severe rather than gradual and initially tolerable (see Figure 5). As a result, monitoring of substation performance is likely

Figure 5: Illustration of Gradual Versus Abrupt Change



Source: Figure adapted from Haasnoot et al. 2018 to be less valuable than the monitoring of exposure-related indicators, such as water level. Adaptation pathways associated with other variables, such as the impacts of increased average precipitation or higher average temperatures, are likely to be better-suited to performance-related indicators.

- Moving from a conceptual level to a detailed implementation support step requires the delineation of rigorous yet easy-to-understand indicator values that will then trigger action when exceeded. Exactly defining these indicator values is challenging both technically and in a policy sense in that these may infer or commit SDG&E to future action in the face of climate change.

4. Next Steps

The next steps for consideration are:

- **Complete the Montgomery substation pathway.** This is an important opportunity in order to take advantage of the high level of engagement to date of SDG&E engineering staff and to leverage the first phase of SDG&E's partnership with Scripps on the implementation of a San Diego Bay water level monitoring array. This could include:
  - Development of a set of indicator values for changes in average conditions and changes to extremes to indicate the appropriate timing of adaptation actions.
  - Revision of GIS vulnerability assessment to compensate for CoSMoS data errors noted above.
  - Additional analysis on the cost-benefit and sequencing of adaptation actions.
- **Determine priority assets for application of adaptation pathways.** Extending the pathways assessment beyond coastal hazards to other climate change hazards (e.g. extreme heat, extreme wind, inland flooding), will require a vulnerability assessment to determine the types of priority assets, together with the priority at-risk locations. This analysis can build on the CEC project assessments that were undertaken for natural gas infrastructure in the SDG&E service area, previous SDG&E assessments, and others published under the California 4th Climate Change Assessment.
- **Pathways governance discussion.** The development of the initial adaptation pathway for Montgomery Substation has highlighted the question of 'what would happen exactly if monitoring indicators are met'. Further discussion of the governance process on how the future actions would be managed within SDG&E to ensure a transparent and accountable adaptation program will be valuable. This could include further discussion on the value of developing contingency plans (operational, capital investment or both) to deal with potential flood-related outages at Montgomery Substation.

IV. Appendix: GIS Flood Maps

Attached as a separate report are the full present the results of ICF's GIS flooding and sea-level rise analysis of Montgomery substation and the surrounding area. Data are sourced from the U.S. Geological Survey's Coastal Storm Modeling System (CoSMoS). A summary of mapping results is shown below.

As noted in the report, ICF's analysis detected an anomaly in U.S. Geological Survey (USGS) inundation data. ICF confirmed with USGS that the detected anomaly represents a data error in the mapping of the model mean results. Consequently ICF, recommends additional inundation analysis as a future step to produce improved mapping of present and future risk, including consultation with USGS.

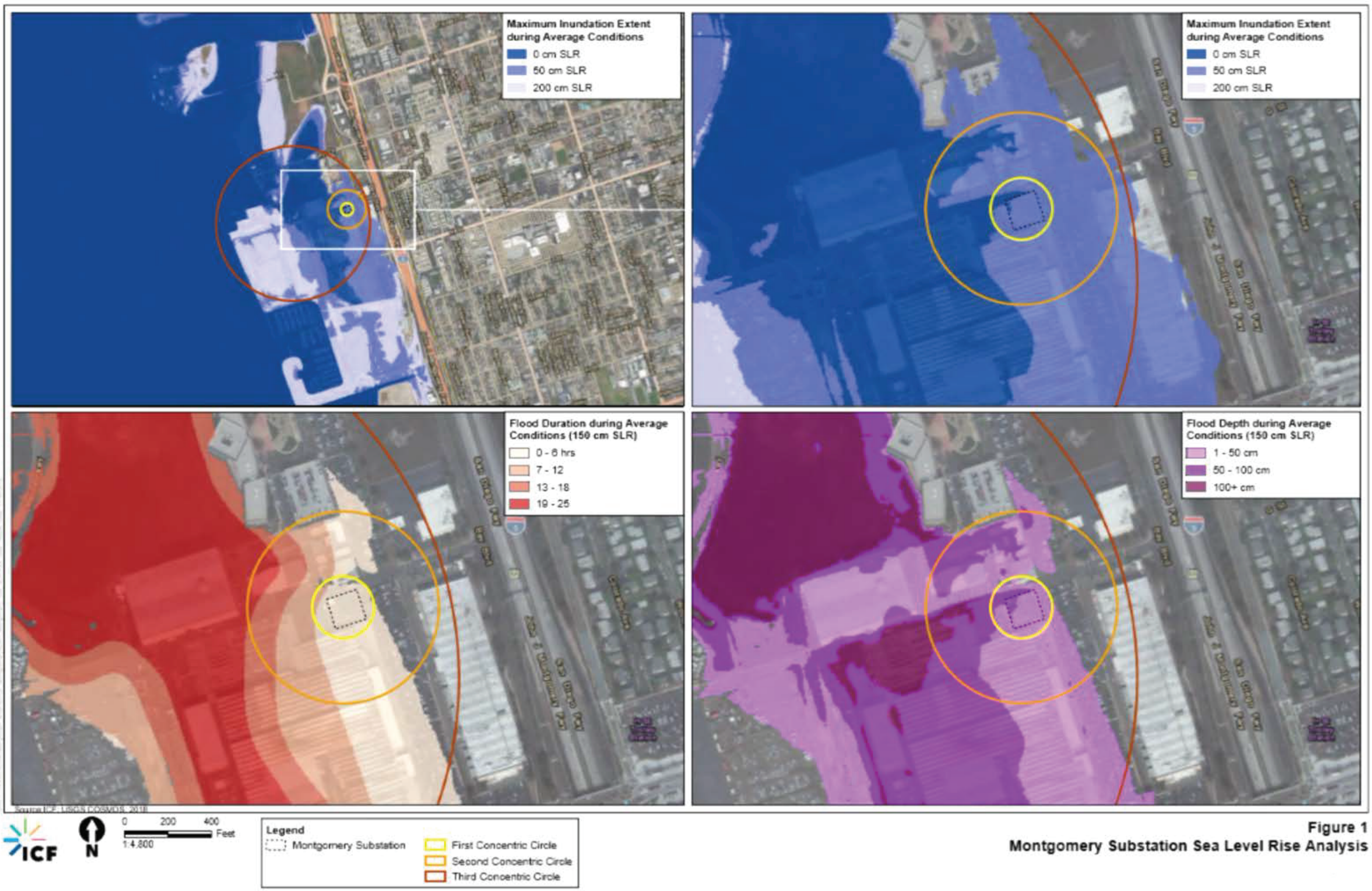


Figure 1
Montgomery Substation Sea Level Rise Analysis

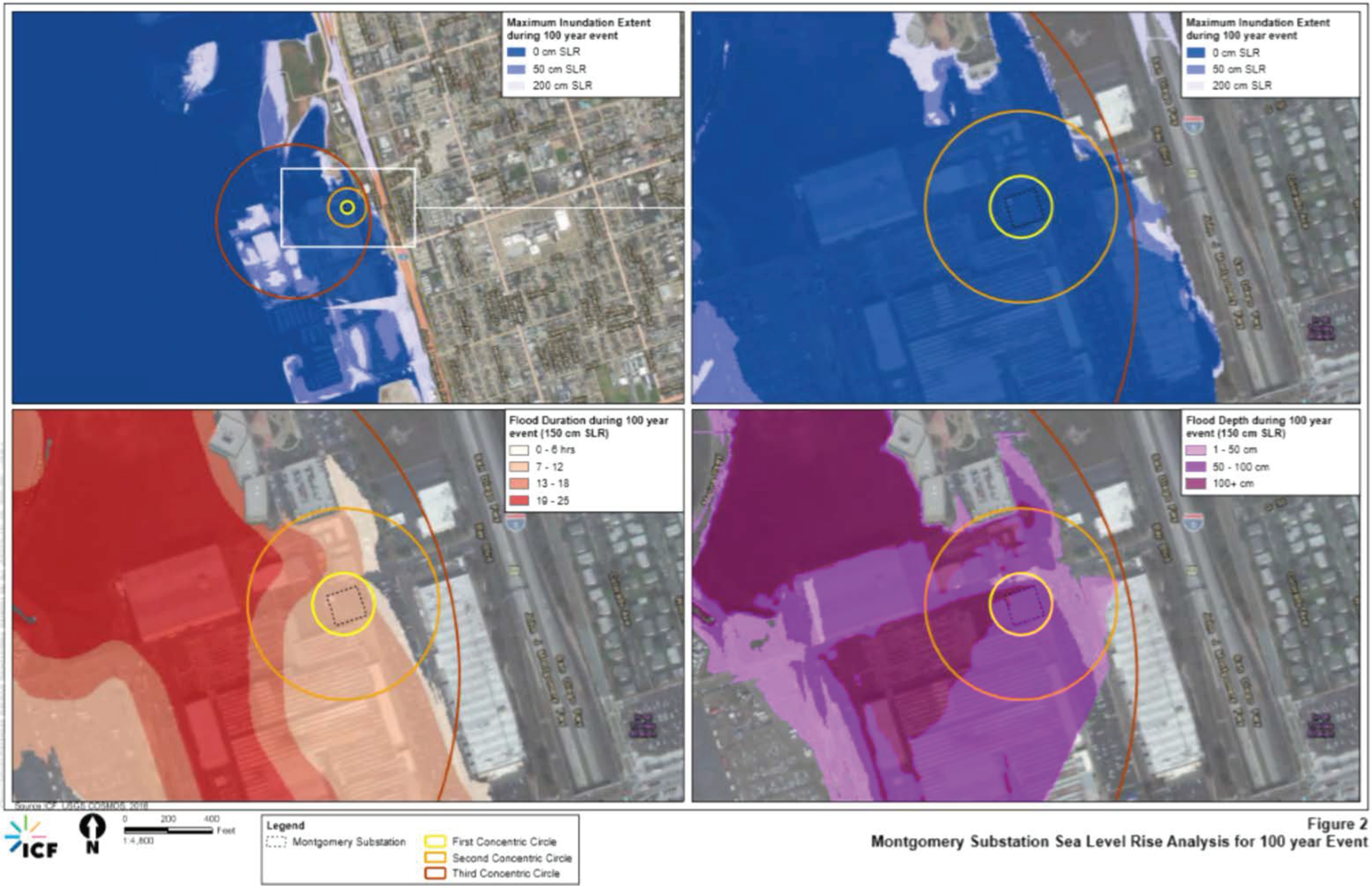


Figure 2
Montgomery Substation Sea Level Rise Analysis for 100 year Event